abc's of AIR CONDITIONING

by ERNEST TRICOMI

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by

Ernest Tricomi

adapted from

Air Conditioning Installation and Maintenance

by

Ernest Tricomi

UBSPD

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Preface

Air conditioning, even in the temperate zones where it is used only a few months out of the year, is recognized as one of the essentials of modern living. First used in stores and offices, air conditioning is now commonplace in homes, factories, and automobiles.

This book shows how the natural laws of physics have been applied to produce the modern air conditioner. Its language has been purposely kept simple and nontechnical so that even the layman can understand everything in it. In its pages the reader will find not only a down-to-earth explanation of the theory of air conditioning, but also a lucid exposition of all the practical applications that have evolved from the fascinating science of keeping air spaces cool.

For much of the material included here, the writer owes a debt of gratitude to literally hundreds of air-conditioning servicemen in the Philadelphia area—far too numerous to mention here.

No attempt has been made to describe or compare the many commercial or residential air conditioners offered by manufacturers, beyond the photographic and art credits beneath some of the illustrations. If this were attempted, the reader would soon be lost in a maze of specifications, ratings, test results, and sales features.

Instead, this book deals with principles, components, and practices which are common to all air conditioners.

ERNEST TRICOMI

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CHAPTER ONE

How Air Conditioners Work—Theory and Operation

Before the operation, installation, and maintenance of the various types of air conditioners can be discussed, several factors must be examined. You must have an understanding of the terms used, the theory of air conditioning, and the factors involved in computing the size unit needed for a given location.

THE PRINCIPLES OF COOLING

As a means of introduction to theory, several short discussions of subjects related to air conditioning, although not necessarily related to each other, are presented. You should read and understand the principles which they illustrate in order to better understand the theory of air conditioning.

Cold

It is common to think of heat and cold as direct opposites; actually they are greater or lesser amounts of the same thing—heat. Cold is the relative absence of heat, just as a shadow is the relative absence of light. We say we feel cold, but actually we feel the absence of the normal heat to which our bodies are accustomed.

To the hypothetical condition of total absence of heat we give the name of absolute zero temperature. Absolute zero has never been achieved by man, although he has come close to it in experiments. Even in outer space, nature does not quite reach the ultimate absence of heat.

Absolute zero is the basis for the measurement of any amount of heat. On the centigrade scale (also called Celsius) it is represented by −273.16°; on the Fahrenheit scale it is −459.67°. (See Fig. 1-1.)

Air conditioning, then, should be thought of as the *removal* of heat from a given space, rather than the *injection* of cold.

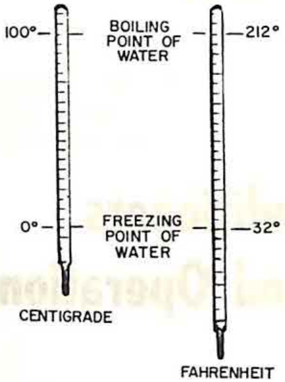


Fig. 1-1. Comparison of Fahrenheit and centigrade scales.

Evaporation

Wet your finger and hold it up in a breeze. The side of your finger facing the breeze will feel cooler than the opposite side. This phenomenon has been observed for so long that it is easy to picture Eric the Red testing the wind in the same way on his Viking ship.

The principle illustrated by this simple experiment is that evaporation is accompanied by cooling. The air moving over one side of the finger causes more rapid evaporation of the liquid on that side. The faster the rate of evaporation, the more heat is lost and the cooler the finger feels, making it easy to distinguish the cool side of the finger from the warmer side.

Air conditioning depends upon evaporation to achieve cooling.

Heat As A Quantity

The *temperature* of a substance depends on its *volume* in relation to a given amount of *heat*. Turn on a gas or electric burner and leave it at the same setting until this experiment is completed. From the cold-water tap, fill a pan to the brim and heat it for exactly three minutes. Remove the pan from the burner and read the temperature of the water with a thermometer. (See Fig. 1-2.)

Now throw away the water and draw a fresh supply, this time filling the pan only part way. Again heat for exactly three minutes. Remove the pan and read the temperature again. The water in the partially filled pan will be found to be considerably hotter than the

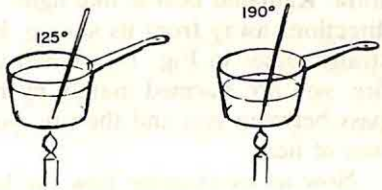


Fig. 1-2. Simple experiment which proves that temperature depends on volume.

water in the full one was. Yet the same *amount* of heat has been applied to both.

In this book we will refer to the *temperature* of substances, rather than their heat. Whenever the word *heat* is used, it will refer to the *energy* being applied to a substance.

From the "More" to the "Less"

Place a jar filled with hot water into a pan filled with cold tap water. Take temperature readings of the hot and cold water as shown in Fig. 1-3. Allow the jar to remain in the cold water for about ten minutes. Stir the water in both containers and take new temperature readings. The cold water will have become warmer, and the hot water will have become cooler.

The principle illustrated is that heat flows from substances of higher temperature to substances of lower temperature. Just as water seeks its level, so does the temperature of substances.

Heat Loss

There are three ways for any substance to lose its internal heat. These are by *conduction*, *convection*, and *radiation*. (See Fig. 1-4.)

In conduction, heat flows from a body of high temperature to another body of lower temperature through surfaces which connect the two bodies together. This is indicated by the short curved lines traveling into objects in contact in Fig. 1-4.

In convection, heat is carried away from a body by a moving liquid or gas (vapor). Convection is indicated by the wavy lines traveling upward in Fig. 1-4.

In radiation, heat travels in a direct line through any space from a substance of high temperature to another body of lower temper-

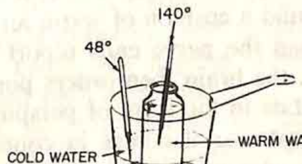


Fig. 1-3. Home-made apparatus which demonstrates that heat seeks a level.

ature. Radiated heat is like light—it travels in a straight line in all directions away from its source. Hence, it is indicated by the long straight lines in Fig. 1-4. When you're sitting in front of a campfire, you are warmed mainly by radiation. Should another camper pass between you and the fire, you immediately feel a momentary loss of heat.

Now let us examine how the human body adjusts to changes in the temperature of its surroundings. This is important because air conditioning is concerned primarily with providing a comfortable environment for humans.

The inside temperature of the human body is approximately 98.6 degrees F. However, the temperature at the outside skin level is only approximately 70 degrees F. If the air or any substance immediately adjacent to the skin should rise above or fall below 70 degrees, we say we feel "hot" or "cold."

Fig. 1-4. The three ways bodies lose internal heat.

When the nerve ends at the skin report to the brain that the outside temperature is dropping, the brain immediately sends a message to the pores of the skin to close up tight, allowing no body moisture to be released. Should the temperature drop considerably, humans have to don more clothing to confine body heat and build a cushion of warm air next to the skin.

When the nerve ends report that the temperature of the air is rising, the brain then orders pores in the skin to open and release body fats in the form of perspiration, a liquid. Most of this liquid evaporates as it comes in contact with the air, and the evaporation is accompanied by cooling of the surface skin, which releases its heat by convection to the surrounding air. Because of convec-

tion, a breeze will cool us off by carrying away body heat faster as it speeds up the evaporation.

Heat from the body's interior now flows to the cooler skin by conduction to cool the entire body. A nice balance is thus maintained so that the interior heat of the healthy body never deviates more than 1 degree or so from its normal 98.6 degrees F, no matter what the outside temperature is.

Comfort Range

Even though the internal heat of the body remains at 98.6 degrees F, this does not mean that the individual has achieved comfort. There is a comfort range, a span of a few degrees below and above 70 degrees F, within which most individuals feel comfortable, and outside of which most individuals feel either too hot or too cold. However, the extent of this comfort range varies from individual to individual (see Fig. 1-5). As we shall see when we examine the ways of measuring temperature, the humidity of the surrounding air has a great deal to do with producing comfort or discomfort.

Fig. 1-5. Some individuals feel discomfort at ranges where others are comfortable.

Relative Humidity

Man is a creature requiring water for his survival. He not only requires it inside his body; his body must be surrounded by it in the form of water vapor. If a human were placed in an enclosed space where every last drop of moisture had been removed from the air, he would soon die—as much from the lack of moisture in the air as from thirst. Not many years ago a circus, as a promotional gimmick, decided to paint one of its elephants all pink from head to toe. Cut off from the outside humidity (and unable to perspire and thus relieve its body heat), the hapless creature was stricken with a high fever and died soon afterward.

Like everything else, however, moisture can be too much of a good thing. Too much moisture in the air surrounding us makes us feel uncomfortable . . . we complain of feeling "wilted." The

reason is that the evaporation of moisture on the skin is slowed down, since the air near it is already so heavily laden with moisture that it cannot absorb much more. This slows down the cooling process, and we perspire profusely even when not exerting ourselves.

Temperature

All matter in the universe exists in one of three states—either solid, liquid, or gaseous. Water is a liquid state of matter, which also takes the form of ice (a solid) or vapor (a gas), as shown in Fig. 1-6. The molecules of water are in a constant state of motion, the amount of agitation depending on the energy possessed by the water. If energy is removed from the water, the molecules slow down and the water feels cold to the touch. If enough energy is removed, the molecules will slow down to the point where the water changes from a liquid to a solid state and becomes ice. Similarly, if enough energy is added to water, it becomes steam, or vapor.

Everything in the universe is subject to these three states mentioned. The state of matter should not be confused with its composition—no change in composition or chemical properties takes place as matter changes in state, which is a physical property. For example, ice, water, and steam all contain approximately 11 percent hydrogen and 89 percent oxygen. The only difference is the physical state of the matter.

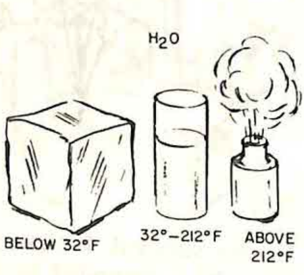


Fig. 1-6. The three states of H_2O—ice, water, and vapor or "steam."

By this definition, steel is in the "ice" or solid state. When a certain amount of heat (energy) is applied to steel, it melts and becomes a liquid. If an enormous amount of energy is applied to it, as in a nuclear explosion, steel will vaporize.

Because energy abounds everywhere about us, all matter is in a constant state of movement. The closer absolute zero temperature is approached, the slower the molecules of matter move. The theoretical limit is the temperature at which all movement of the molecules ceases.

Two important principles can be derived from this discussion. One is that the state of matter is directly affected by its tempera-

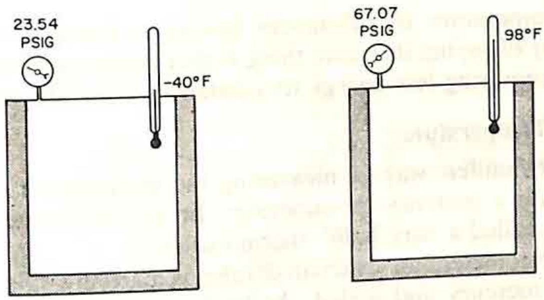


Fig. 1-7. Comparison of vapor temperatures at different pressures.

ture. Another is that matter cannot be destroyed (or created either) —it can only be changed in chemical or physical structure.

Energy Versus Heat

The temperature of a substance changes with the removal or addition of heat. One way to add heat, as we have seen, is to place a flame or other source of heat under a substance. One way to remove heat, and this is the way in which air conditioners perform this task, is to *decompress* a substance (Fig. 1-7).

Solids and liquids are considered incompressible because their molecules cannot be crowded any closer together. Gases and vapors, on the other hand, are compressible—that is, they may be confined in spaces of varying cubic volume. (Gas is any substance that is ordinarily found on earth in a gaseous state; vapor is the gaseous form of a substance that is ordinarily found in a solid or liquid state. In this book, we will deal with vapors exclusively.) Gases and vapors are characterized by the enormous distances (relatively speaking) between their molecules. The farther apart the molecules are, the farther they can travel before colliding with one another, and the more energy they use up in traveling the greater distances.

If a gas or vapor is compressed (confined to a smaller mass), the distances between molecules are cut down in direct proportion to the amount of compression. Now, because the molecules travel shorter distances before collision, they use up less energy. The unused energy is released in the form of heat. This is why gas or vapor feels hotter under compression. It also confirms the theory that matter or energy cannot be destroyed—the unused energy cannot just disappear; instead, it is converted into another form of energy (heat).

By the same token, when the gas is decompressed, it must absorb more energy. It gets this energy from its surroundings, because of the law which states that heat must pass from substances having

a higher temperature to substances having a lower temperature. Another way of saying the same thing is that energy must pass from substances requiring less energy to substances requiring more.

Measuring Temperature

The most familiar way of measuring the temperature of a substance is with a mercury thermometer. In air-conditioning terminology, it is called a "dry bulb" thermometer.

In a thermometer, an evacuated tube is partially filled with a quantity of mercury and sealed. As heat or cold is applied to the bulbous reservoir at one end of the tube, the mercury expands or contracts a predictable distance along the length of the tube. Distances are calibrated in degrees of temperature, either in the centigrade or the Fahrenheit scale.

In the centigrade scale, the freezing point of water is 0, and the boiling point is 100. The distance between the two points along the tube is divided into intervals of 100 degrees (hence the prefix *centi*, meaning hundred).

In the Fahrenheit scale, 32 degrees represents the freezing point of water, and 212 degrees represents the boiling point. Gabriel Fahrenheit, who developed this scale, believed that he had achieved absolute zero. For this reason he marked the temperature he had reached as 0 on his scale. For his high-temperature reference point he took the temperature of the human body, which he called 96 degrees (this misses the correct value of 98.6 degrees, probably because of experimental error). Dividing the scale between 0 and 96 in unit divisions and projecting the divisions upward for higher temperatures, he found that the freezing point of water came at 32 degrees and the boiling point of water came at 212 degrees. This accounts for the seemingly arbitrary numbers of the Fahrenheit scale.

The Fahrenheit scale is more widely used in air-conditioning design and servicing. The centigrade (or Celsius) scale is reserved for laboratory and other experimental work.

Along with temperature, meteorologists had to devise a method of measuring relative humidity, since the two factors are so closely related in their effect on the human body. (Relative humidity is the ratio of the amount of vapor actually present, to the greatest amount possible, at a given temperature. Complete saturation is 100 percent). This led to the "wet bulb" thermometer (Fig. 1-8). A wick, wrapped around the bulb of a dry-bulb thermometer, is soaked by dipping the bulb end into distilled water. The thermometer is then held in an air stream from a fan or whirled rapidly through the air for several seconds. Depending on the humidity of the air, evaporation will take place more or less rapidly at the wick. The thermom-

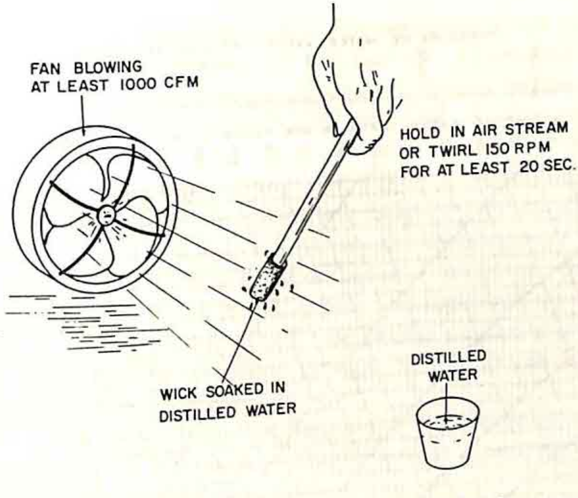


Fig. 1-8. Reading temperatures with a "wet-bulb" thermometer.

eter reading is directly related to the amount of moisture in the air. Wet-bulb readings are always lower than dry-bulb readings. By subtracting one from the other and using a chart (Fig. 1-9), it is possible to find the relative humidity in percent.

Dry Bulb Reading	Percent of relative humidity.						
70	81	72	64	55			
75	82	74	66	58	51		
80	83	75	68	61	54		
85	84	76	70	63	56	50	
90	85	78	71	65	58	52	
95	86	79	72	66	60	54	
100	86	80	73	68	62	56	51
	4	6	8	10	12	14	16
	Dry-bulb minus wet-bulb reading						

Fig. 1-9. Relative humidity chart.

Another method of finding the relative humidity is to use the psychrometric chart (Fig. 1-10). A psychrometric chart is a graph of the thermodynamic properties of moist air. If any two properties of the air being measured are known, the other characteristics

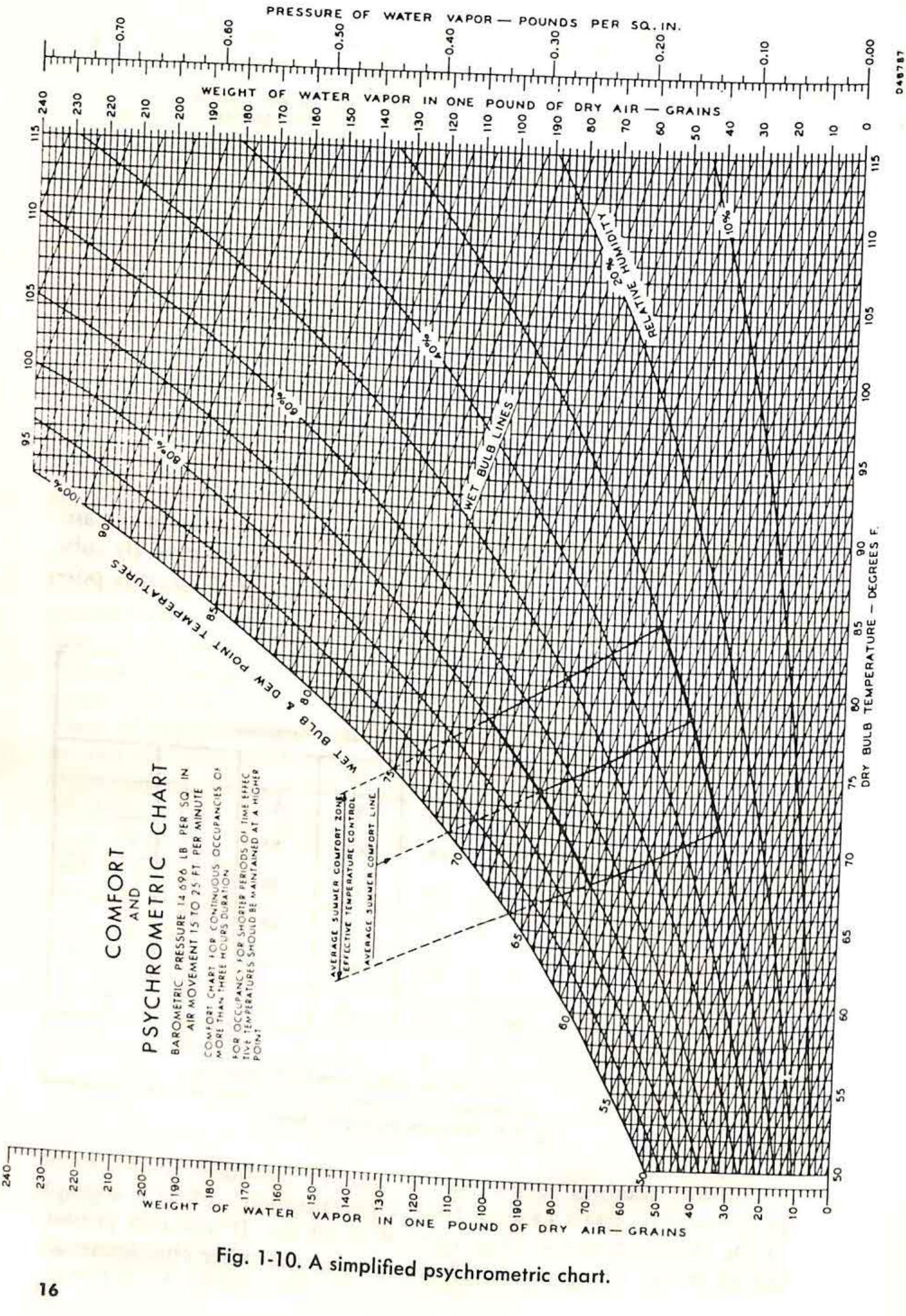


Fig. 1-10. A simplified psychrometric chart.

can be read directly from the chart. For instance, if we know the dry and wet-bulb temperatures, we can find its (1) relative humidity, (2) dew point (temperature at which a vapor begins to turn into a liquid, seen as fog) and (3) the pressure of water vapor, in pounds per square inch. The chart can also tell us the weight of the water vapor in the air.

Here is how to use the psychrometric chart: At the bottom, find the dry-bulb temperature you read from the thermometer. Follow the vertical line represented by this figure straight up until you arrive at the intersection of the diagonal line representing the wet-bulb temperature. Now read the value of the nearest *curved* line to get relative humidity. Reading straight across to the left, read the dew-point temperature on the scale.

The dew point is illustrated in Fig. 1-11. The moist air contacts the cooled surface of the glass and moisture condenses on it, leaving dry air flowing beyond the glass.

Still another measure of relative humidity is the recently developed "Discomfort Index" (DI), which is winning favor among meterologists. The formula for finding the DI of air in a given space is:

$$DI = 0.4(DB + WB) + 15$$

where, DB and WB are the dry- and wet-bulb readings, respectively.

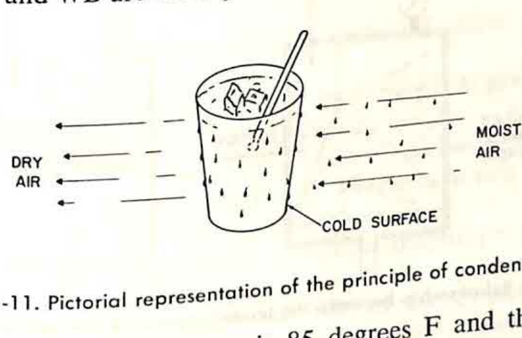


Fig. 1-11. Pictorial representation of the principle of condensation.

If the dry-bulb temperature is 85 degrees F and the wet-bulb temperature is 75 degrees F, to find DI:

$$\begin{aligned} DI &= 0.4(85 + 75) + 15 \\ &= 0.4(160) + 15 \\ &= 64 + 15 \\ &= 79 \end{aligned}$$

In the psychrometric index, the comfort zone lies between 30 percent and 70 percent humidity, and 68 degrees and 85 degrees F. In the Discomfort Index, however, only one figure need be considered. Nine out of ten persons will feel comfortable at DI values below 70. Above this value, more and more people will feel

discomfort, with about half of them uncomfortable at 75 and everyone uncomfortable at 79. Serious discomfort, affecting work ability, will occur above 85.

Pressure of Gases

All gases and vapors exert pressure equally in all directions. The molecules of gas confined in a closed vessel are constantly bombarding the sides of the vessel with billions of collisions per second. This bombardment speeds up as the volume of the vessel is made smaller, as in the cylinder of a compressor. Having compressed the vapor, we say its *pressure* has been increased.

As you have already seen, the more a vapor is compressed, the less the distance its molecules can travel before colliding with one another. This requires less energy and the extra energy is released as heat. Thus there is a definite, never-changing relationship between the temperature of vapor and its pressure.

In the case of R-12 saturated vapor, for instance, if its temperature is 40 degrees F, its pressure will be constant at exactly 36.98 psig (pounds per square inch gauge) or 51.68 psia (pounds per square inch absolute); at 30 degrees F, its pressure will be 28.46 psig or 43.16 psia (see Fig. 1-12).

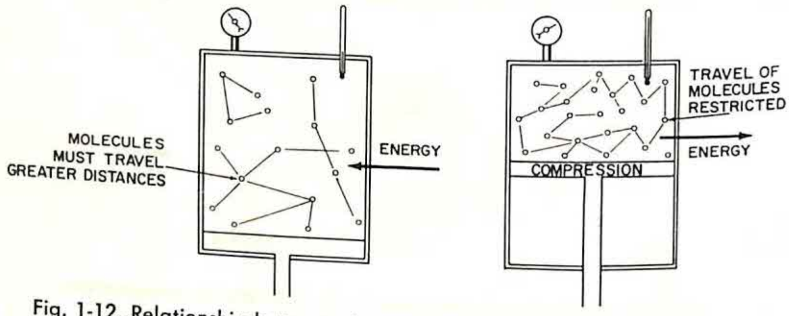
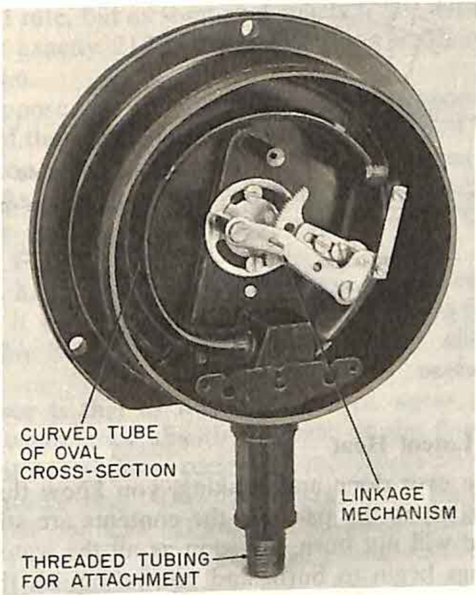


Fig. 1-12. Relationship between the temperature and pressure of vapors.

(Pressures measured above or below atmospheric pressure are called *gauge pressures*. Since atmospheric pressure is 14.7 psi [pounds per square inch] at sea level, a gauge reading of 5 psig actually represents an *absolute pressure* of 19.7 psia [5 + 14.7]. Of course, as one goes higher in the atmosphere, the pressure drops. Hence a reading of 5 psig would be somewhat lower than 19.7 psia at higher altitudes.)

Pressure gauges are useful in air-conditioning. One type is the Bourdon gauge in Fig. 1-13, a hollow tube sealed at one end. When pressure is introduced at the open end, it tends to straighten the tube. This action is transmitted to a needle moving across a dial,



Courtesy Ashcroft Gauges, Manning, Maxwell & Moore, Inc.

Fig. 1-13. A typical Bourdon gauge.

where the pressure can be read directly in psi above atmospheric pressure.

Bourdon gauges may be had in two types. A *pressure* gauge reads only pressure above atmospheric pressure. A *compound* gauge reads pressures below atmospheric pressure as well. The latter reading is given in *inches of mercury*, which is common practice in the air-conditioning industry.

Other pressure gauges employ a flexible diaphragm or a column of mercury. In the diaphragm type (Fig. 1-14), pressure or a partial vacuum is introduced on one side of the diaphragm, which expands or contracts, moving a needle above or below the zero point on the scale. Zero represents atmospheric pressure, so the readings are in psig.

In the mercury gauge, called a *manometer* (Fig. 1-15), a U-shaped tube open at both ends contains a quantity of mercury. At atmospheric pressure, both columns are at the same level. When pressure or a partial vacuum is introduced at one end, the mercury rises in one column and falls in the other. The difference between their levels, expressed in inches of mercury, gives the amount of pressure or vacuum.

A difference of 2 inches of mercury is approximately equal to 1 psi.

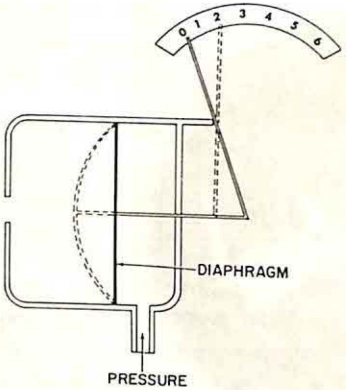


Fig. 1-14. Principle of operation of a diaphragm-type pressure gauge.

Sensible and Latent Heat

If you have ever done any cooking, you know that as long as there is water left in the pan and the contents are stirred periodically, the food will not burn. As soon as all the water evaporates, however, things begin to burn, and you relinquish the kitchen to your betters or go out for dinner.

When you fill a pan with cold tap water and place it over a flame, the water first becomes warm, then hot. You can *feel* the temperature of the water change. This is called *sensible* heat.

When the water reaches a temperature of 212 degrees F, it begins to evaporate so rapidly that bubbles of vapor are formed within the liquid itself, and we say the water is boiling. But now a curious thing happens. Until now the thermometer has been climbing at

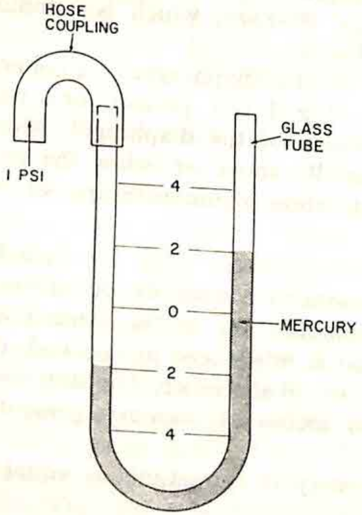


Fig. 1-15. Manometer for measuring pressure or vacuum in inches of mercury.

a fairly rapid rate, but as soon as it reaches 212 degrees F, it stops, and stays at exactly 212 degrees F as long as there is any water left in the pan.

Let us suppose you are able to trap all the vapor that rises from the surface of the water. Reading the temperature of this vapor, you find that it, too, stays at 212 degrees F as long as any water remains in the pan. As soon as all the water has boiled away, however, the thermometer reading of the water vapor begins to climb above 212 degrees F.

What has happened to all the heat you have been adding to the water while it was boiling? There has been no perceptible change in the *sensible* heat, so the temperature of the water has not increased.

The answer is that as the molecules of water change from a liquid to a vapor, they absorb the heat of the flame, but "translate" the heat energy into accelerated movement rather than releasing it as sensible heat. The heat energy used by a substance in changing from one state to another is called *latent heat.*

When all the water has boiled away in our experiment, the thermometer again begins to climb. The vapor is now *superheated*—that is, heated above the point where a liquid changes to vapor.

The same thing occurs when a solid changes to a liquid. While a piece of ice melts in a glass, the water in the glass theoretically remains at 32 degrees F as long as there is any ice left. The heat being absorbed by the liquid during this period is also called latent heat.

The heat that effects the change from liquid to vapor, is called *latent heat of evaporation.* In a physical change from solid to liquid, is called *latent heat of fusion.*

British Thermal Units

As opposed to measuring the *temperature* of substances in degrees centigrade or Fahrenheit, we need some method of measuring the abstract quality called heat. The British thermal unit, or Btu, is used. One Btu is defined as the amount of *heat* required to raise the temperature of a pound of water 1 degree Fahrenheit at or near its point of maximum density. (See Fig. 1-16.)

Thus, we can speak of the *specific heat* of water as 1.0 Btu per lb. All other substances have different specific heats; for example, air is 0.24, glass 0.16, and petroleum 0.51.

Another measure of heat transfer in air-conditioning terminology is the *ton of refrigeration.* This is a rate of cooling, or the amount of heat a ton of melting ice absorbs in a 24-hour period. Thus, a ½-ton air conditioner theoretically takes from a space the same amount of heat absorbed by 1,000 pounds of ice that melts com-

pletely in a 24-hour period. A ton of refrigeration is equivalent to 12,000 Btu per hour. This unit is falling into disfavor as a measure of capacity, however; in most air-conditioners capacity is now expressed as so many Btu's per hour.

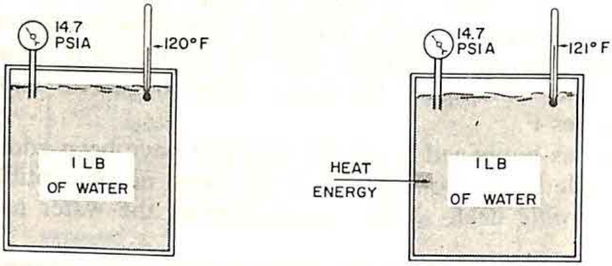


Fig. 1-16. British thermal unit (Btu).

HOW AN AIR CONDITIONER WORKS

A vat of refrigerant placed in the center of a room is a very primitive form of air conditioner. As the refrigerant liquid evaporates, or turns into a vapor, it borrows the necessary heat energy from the surrounding air, and cooling takes place. The trouble with such a "system" is that it is wasteful of refrigerant and can not cool fast enough to be effective.

A modern air-conditioning system merely provides an enclosed space so that no refrigerant is wasted, and a means of circulating the refrigerant is provided to hasten the cooling process.

The Refrigerant Cycle

Fig. 1-17 is a simplified diagram of a typical air-conditioning system. The *compressor* receives the refrigerant as a hot vapor through an intake valve, and compresses it in the cylinder so that it occupies a much smaller volume. The compressed vapor now enters the *high side* of the system, where it is first circulated through the *condenser*. A stream of outdoor air is blown over the condenser by the *condenser fan*, which is driven by the *condenser fan motor*.

Through *conduction*, the hot, compressed vapor releases its heat through the walls of the condenser tubing and into the cooling fins. The fins, in turn, give up this heat, through convection, to the outdoor air. This air is now expelled back outdoors, warmer than it was when first admitted to the air conditioner.

The refrigerant, having lost a great deal of its heat, now changes from a vapor to a liquid and passes into the *liquid line*. In order to to maintain its pressure, it is separated from the evaporator by a length of capillary tubing, called a *restrictor*. This tubing separates

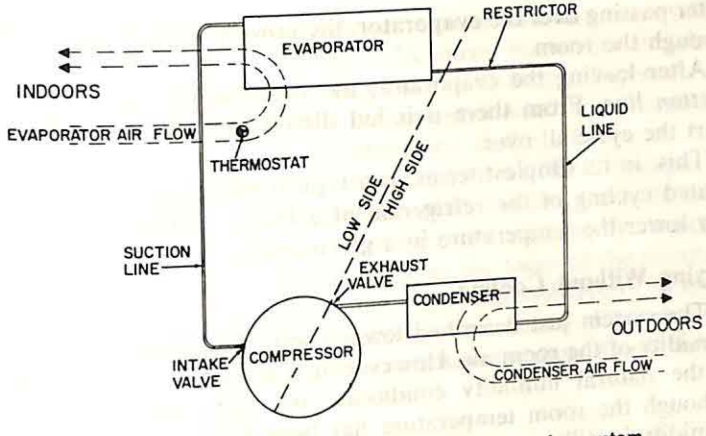


Fig. 1-17. Block diagram of a typical air-conditioning system.

the high side of the system from the low side as long as the compressor is operating. When the compressor stops, the restrictor equalizes the pressures in the high and low side. In this way, when the compressor starts up again the pressure is built up gradually, permitting an easier start.

After leaving the restrictor tubing, the *liquid refrigerant* enters the *evaporator*, on the *low side* of the system. Here, its pressure drops suddenly. As mentioned before, pressure and temperature are directly related to each other. As the pressure drops, the molecules of the refrigerant have greater distances to travel and require more energy. They "borrow" this energy in the form of heat from the air surrounding the evaporator. Now the refrigerant begins to boil, changing from a liquid back to a vapor.

As you have seen, any change of state is accompanied by *latent heat*—in this instance, latent heat of evaporation. A substance undergoing a change of state can absorb latent heat without affecting its own *temperature*. Thus, the expanding vapors can absorb many Btu's before their temperature actually changes. Progressing through the evaporator, the vapor absorbs all the latent heat it can. Soon it becomes *superheated*—that is, hotter than the temperature required to change it from a liquid to a vapor. The amount of superheated vapor in the evaporator at any one time is carefully controlled in the design of the system, as we shall see later.

The *evaporator blower*, in the meantime, is drawing in air from the room or space to be conditioned and forcing it across the face of the evaporator. This air, being warmer than the surface of the evaporator, releases its heat through convection to the evaporator fins. The fins then release their heat, through conduction, to the energy-starved refrigerant vapor circulating through the evaporator.

After passing over the evaporator, the now-cooler air is recirculated through the room.

After leaving the evaporator, the superheated vapor enters the *suction line*. From there it is fed directly into the compressor to start the cycle all over.

This, in its simplest terms, is a typical refrigerant cycle. The repeated cycling of the refrigerant at a fairly rapid rate will gradually lower the temperature in a given space.

Drying Without Cooling

The system just described lowers both the temperature and the humidity of the room air. However, it is primarily a cooling device. If the natural humidity conditions are high, we may find that although the room temperature has been lowered sufficiently, the humidity is still too high for comfort. If the unit is set to continue operation in an effort to lower the humidity, the room will be supercooled. Some air conditioners have been designed to cope with such conditions as these.

In these units, called cooling-drying models, the evaporator is divided into two sections, one immediately behind the other, so that circulating air goes first through one section, then through the other. A system of valves allows the refrigerant to be routed independently through each section of the evaporator so that it can be run in either direction through one of the sections. This section can then provide either a heating or cooling effect, depending on whether the refrigerant is applied directly from the compressor or goes first through the condenser.

At the end of a cooling cycle, if the humidistat senses that further reduction in humidity is desirable, it switches the valve so that the one section of the evaporator is used for heating. The other section continues to operate as it always does, that is, as a cooling coil. The room air passes first over the cooling coil, where its temperature is reduced below the dew point, condensing some of the moisture and drying the air, but cooling it at the same time. The air passes next over the warm coil, and is warmed by it before passing on out into the room.

Controls

It becomes apparent at once that the rate of cooling must be controlled so that various degrees of comfort may be attained and maintained automatically. This is generally done by controlling the length of time the compressor functions.

In most air conditioners, the condenser fan and evaporator blower are constantly in operation as long as the air conditioner is on. Only the compressor cycles on and off.

A thermostat is the sensing device that determines the cycling periods of the compressor. As Fig. 1-18 shows, it consists of a short length of tubing sealed at one end and filled with refrigerant. At the other end of the tubing is a bellows connected to a triggering device. A spring counteracts the expansion of the bellows.

With the bulk of the tubing in the return air flow, changes in temperature will cause the refrigerant—and, in turn, the bellows—to expand and contract. As the room becomes warmer, the expanding refrigerant expands the bellows against the force of the counteracting spring. When the bellows has expanded sufficiently, a lever closes the switch mechanism, completing the circuit. Electric current is now permitted to reach the compressor motor, which drives the compressor.

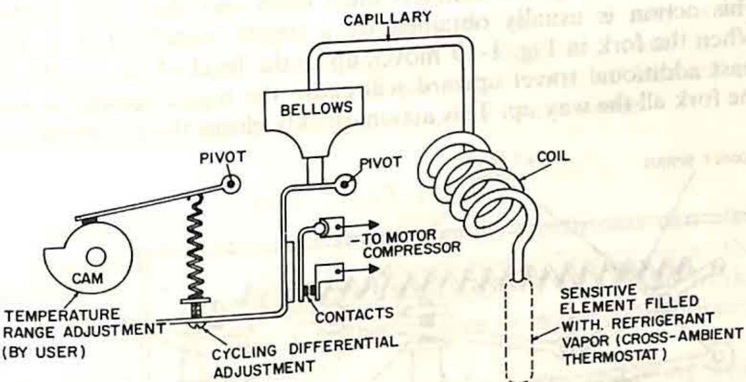


Fig. 1-18. Operation of bellows-type thermostats.

As the air in the room becomes cooler, so does the return air to the conditioner. Now the refrigerant in the thermostat tubing contracts. The bellows, under pressure of the counteracting spring, also contracts and a lever triggers the switch to open the contacts. In the cross-ambient thermostat, there is a variation in the sensing tube. Here, a sensing bulb is connected to the end of the length of tubing as shown by the dotted lines in Fig. 1-18. In this way, only the bulb need be placed in the return air flow; the tube and the rest of the thermostat components may be placed at any convenient location on the front panel.

A knob permits the thermostat to be set to control the temperature at which the thermostat will cycle the compressor on and off. It is usually coupled with the counteracting spring in the bellows to increase or decrease the spring pressure. A dial indicates the direction in which to turn the knob for cooler or warmer operation.

Numbers are sometimes used, but only as reference points; they have no significance as to the temperature desired.

To prevent too frequent cycling of the compressor, the manufacturer sets a high and low limit in the thermostat. At the high limit the thermostat contacts will close, and at the low limit they will open. The *differential*, as it is called, between high and low is usually about 5 degrees F. The *range* of a thermostat is the span of temperatures at which it will open and close.

If the thermostat were wired directly to a source of electric current, without a switch to open and close the contacts, the contact points would move toward each other so slowly, as the temperature rises, that the current would jump across the open space between them. This arcing, as it is called, would soon burn out the contacts. To prevent arcing, the contacts must open and shut with a snap. This action is usually obtained by a toggle switch (Fig. 1-19). When the fork in Fig. 1-19 moves up to the level of the pivots, the least additional travel upward will cause the toggle spring to snap the fork all the way up. This action quickly closes the electrical con-

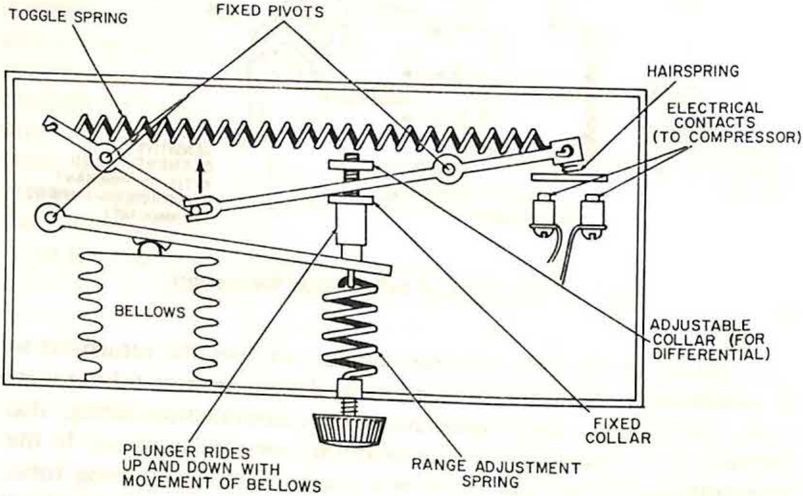


Fig. 1-19. Toggle switch of the type used in many air-conditioner thermostats.

tacts, completing the circuit. The opposite action occurs when the bellows contracts. Magnetic or mercury switches are employed occasionally for the same purpose.

The system described in this chapter is the one used in room air-conditioner units, such as a window model. Such air conditioners are of a fixed design. That is, the inside diameters of all tubing, the capacities of the evaporator and condenser, and even the number of cubic feet per minute of the air-flow system, are all worked

out in exact detail so that the system will be perfectly balanced under all conditions.

Central air-conditioning systems and certain free-standing units may have more flexible controls so that the system may be balanced through a wider range of local conditions. One such control may be at the evaporator entrance to admit more or less refrigerant (and to control the pressure difference between the high and the low side). This adjustment regulates the amount of superheated vapor in the evaporator. Too much superheated vapor will adversely affect the system's cooling capacity. Too little or none at all may mean that some of the liquid refrigerant does not evaporate. Liquid entering the compressor may increase the head pressure so much that the compressor may be damaged.

Another control found in larger systems is at the condenser, particularly in water-cooled systems that use community water supplies without circulation. A valve in the water line controls the amount of water flowing past the condenser coils. A balance of water flow is desirable at this point in order to cut waste.

THE HEAT PUMP

"Heat pump" is the name given to an air conditioner that also works as an auxiliary heater for between-season heating, or as the prime source of heat in winter. Simply stated, a heat pump works by reversing the sequence of refrigerant flow, to warm a conditioned space instead of cooling it.

If the construction of an evaporator facilitates extracting heat *from* the surrounding air, it also permits conduction of heat *to* the surrounding air. Similarly, the heat transfer ability of a condenser works as well in absorbing heat as in dispelling it.

Large bodies of water can be great sources of heat. Even on the coldest winter day, the temperature of the ocean in temperate climates rarely falls much below 40 degrees F. This means that, although it is too cold for human survival, the ocean still has stored up an enormous amount of heat. The same thing is true, to a lesser degree, about the air surrounding us. Although the temperature may fall to −50 degrees F, there is still *some* heat in "cold air."

A heat pump extracts some of this heat from the outside air. In order to do this, the refrigerant in the system, normally used to extract heat from indoor air, is circulated in the opposite direction by means of a reverse-cycle valve (Fig. 1-20). Refrigerant vapor flows from the compressor to the evaporator (indoor coil) under compression. Blowers pass room air over the indoor coil, causing the refrigerant to give up its heat and condense to a liquid. The liquid refrigerant passes through the restrictor tubing (or expansion

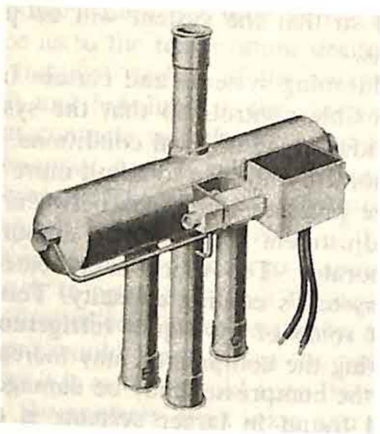


Fig. 1-20. A typical reverse-cycle valve.

valve) into the condenser (outdoor coil). Here it absorbs heat from the surrounding outdoor air, boils into vapor, and passes into the compressor again.

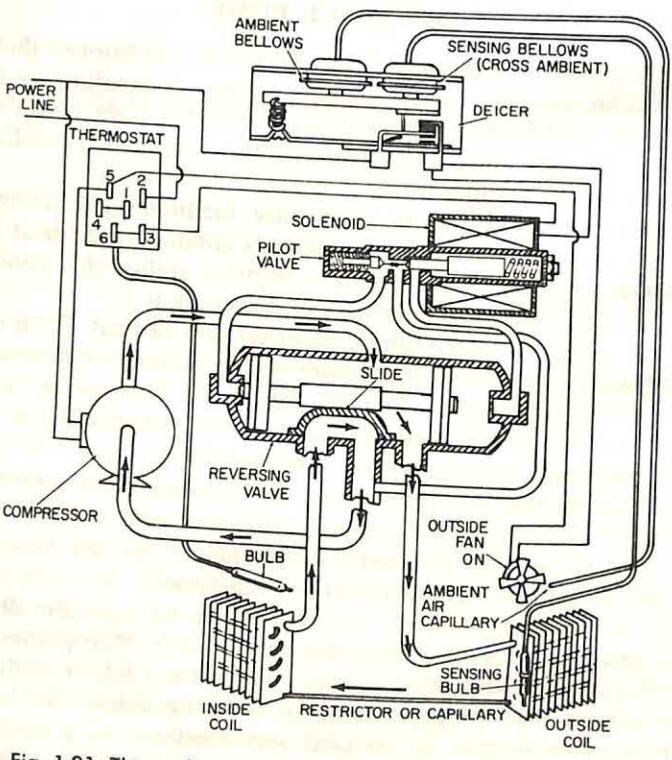


Fig. 1-21. The cooling phase of the heat-pump air conditioner.

Remember that heat flows from substances of higher temperature to substances of lower temperature. In order for the heat pump to work properly, the refrigerant must have a vaporizing temperature, or boiling point, lower than the temperature of the surrounding air, even if only a few degrees lower. While this would appear to limit the performance of a heat pump, recent improvements in refriger-

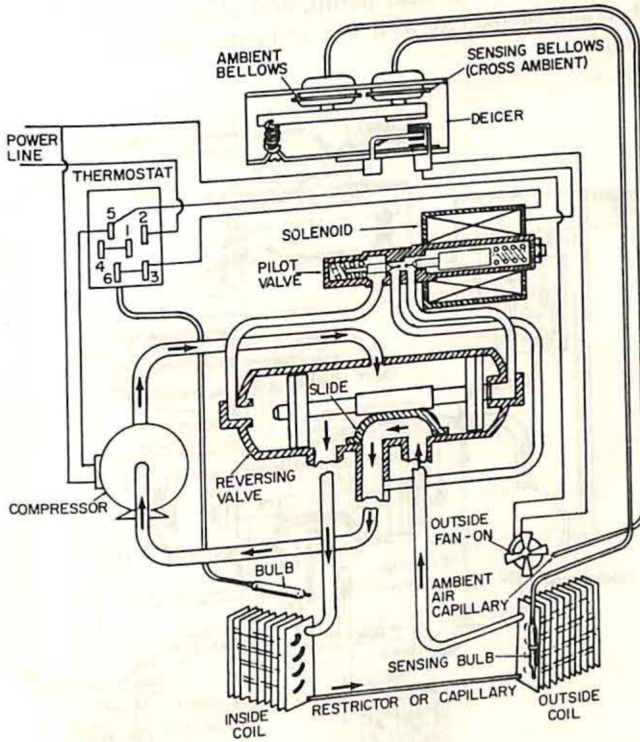


Fig. 1-22. The heating phase of the heat-pump air conditioner.

ants and mechanical pumping have made the heat pump a very efficient mechanism indeed. Some models generate so much heat that the front panel and deflector grilles must be fabricated from a special plastic that does not warp or blister.

Figs. 1-21 and 1-22 show the difference between the cooling and the heating phase of a heat-pump air conditioner. Note that an electrically stimulated solenoid activates the reverse-cycle valve. The electrical impulse for the solenoid is supplied by the room thermostat, which automatically reverses the refrigerant flow whenever the room temperature drops to a predetermined low.

In earlier models of the heat-pump air conditioner, the refrigerant flow was reversed by a hand valve.

As with any evaporator, cooling of the surrounding air is accompanied by condensation. During the reverse operation, this condensate may freeze when the temperature of the outdoor coil drops below 32 degrees F and the outside temperature drops below 45 degrees F (with variations due to the amount of moisture in the air, construction of the heat pump, and other factors). The outside coils become blanketed with ice, reducing the heat transfer from air to coils.

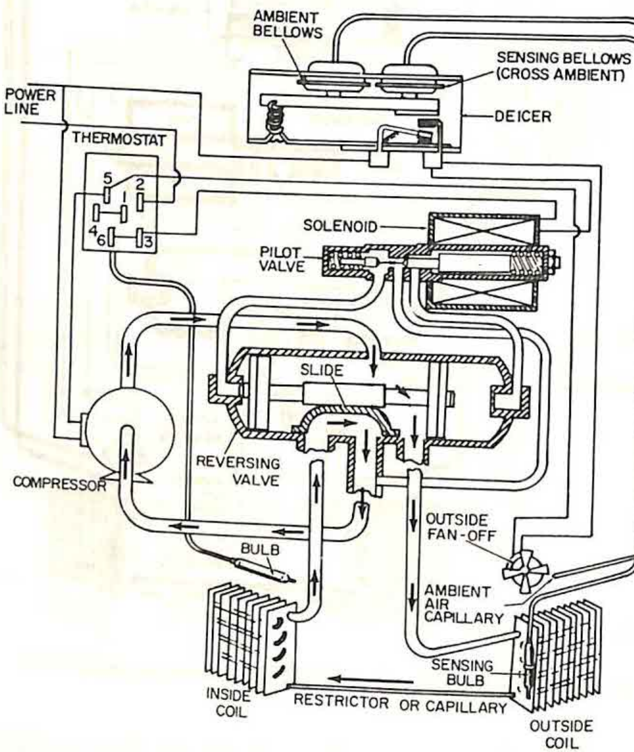


Fig. 1-23. The deicing phase of the heat-pump air conditioner.

A deicer is introduced into the system to overcome the effects of ice. (See Fig. 1-23.) It consists of a pair of bellows containing refrigerant. One bellows is connected to a sensing tube on the outside coil. The other is connected to an ambient sensing tube, which senses only the temperature of the air surrounding the coil.

As the ice blanket increases in thickness, less heat is transferred between the air and coil, causing the temperature of the coil to

drop. When the temperature difference between air and coil becomes great enough, the deicer (1) opens the circuit to the outside coil fan, and (2) sends an electrical impulse to the thermostat, causing the solenoid to operate the reverse-cycle valve.

Now refrigerant is flowing in the normal cooling cycle, which means the condenser (outside coil) will become warm enough to melt the ice. As the temperature difference between air and coil lessens, the deicer circuit opens, the thermostat regains control, and the reverse-cycle valve once more reverses the flow of refrigerant to the heating cycle. At the same time, the outside-coil fan resumes operation, and the heat pump continues the heating cycle until ice again causes the deicing sequence.

CHAPTER TWO

Air Conditioning Systems and Common Applications

Let us now become acquainted with the major systems of a typical air conditioner and some common applications. In this chapter you will, in a sense, take a room air conditioner apart.

The refrigeration system will be discussed first, followed by the electrical system, air-flow system, the cabinet and accessories, and other miscellaneous elements.

ROOM AIR CONDITIONERS

The diagram in Fig. 2-1 shows the refrigeration system in a typical room air conditioner. Now we will examine each of the sections in more detail and determine its function in the operation of the over-all system.

Motor Compressor

At the heart of any air conditioning or mechanical refrigeration system is the motor compressor, which pumps the refrigerant through the system just as the heart pumps blood through arteries and veins. Here we must leave the analogy, because the motor compressor receives the refrigerant in vapor form.

Motor compressors are available in several styles and types. The two most popular in air conditioners are the *reciprocating piston* and the *rotary* types.

In a reciprocating-piston motor compressor (Fig. 2-2), the refrigerant vapor is compressed by a piston in a cylinder. It operates

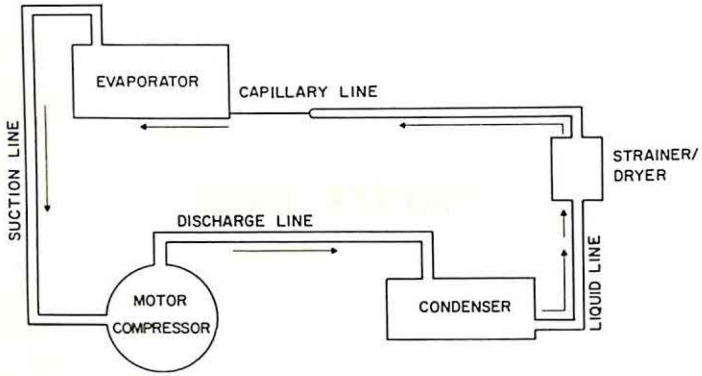
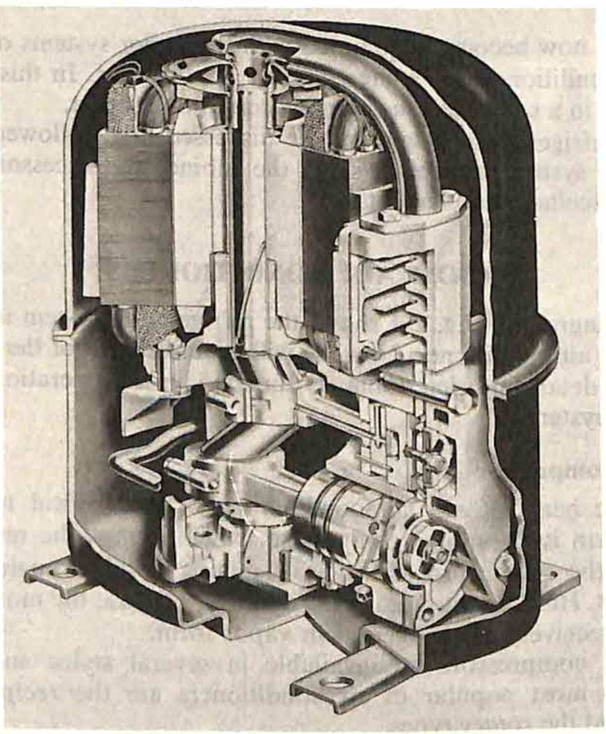


Fig. 2-1. Block diagram of the refrigeration system in a typical room air conditioner.

exactly like the piston of a gasoline engine except that instead of being acted on by an expanding, burning gas, the piston compresses a vapor and expels it from the cylinder. A system of valves (Fig. 2-3) alternately open and close to admit vapor at the bottom of the



Courtesy Tecumseh Products Co.

Fig. 2-2. Cutaway view of a hermetically-sealed motor compressor.

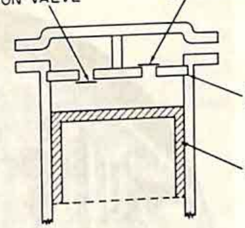


Fig. 2-3. How the valves function in a motor compressor.

stroke, and expel it at the top of the stroke. One or two pistons may be used, depending on the amount of compression required. The unit pictured in Fig. 2-2 is typical of those in larger (30,000 to 50,000 Btu/hr) systems.

In a rotary compressor (Fig. 2-4), compression is accomplished by an alternately expanding and shrinking chamber formed by an eccentric (off-center) ring rotating within a concentric housing. Note the discharge and suction openings at A and B. Between them is a blade (C) under spring tension so that it is in constant contact with the eccentric ring. The blade forms a gastight seal at the point of contact with the ring. As the crankshaft rotates, it turns the eccentric ring, which barely touches the interior of the housing. As the outermost edge of the ring passes the suction opening (B), there is little or no space between it and the housing. As the outer edge of the ring "retreats" away from the suction opening, an expanding chamber which has as its walls the blade, the housing, and the edge of the eccentric ring is formed. This chamber reaches its greatest expansion or volume just as the outer edge approaches the discharge opening (A). Vapors in the suction line (B) rush into this growing space, in an effort to fill it.

While this has been happening, another chamber has been formed on the discharge side of the blade. This chamber, because it precedes the advancing ring, grows smaller instead of larger. As a result, the vapor in the chamber is pushed out of the discharge opening under compression.

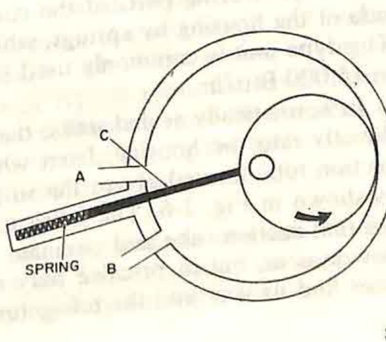
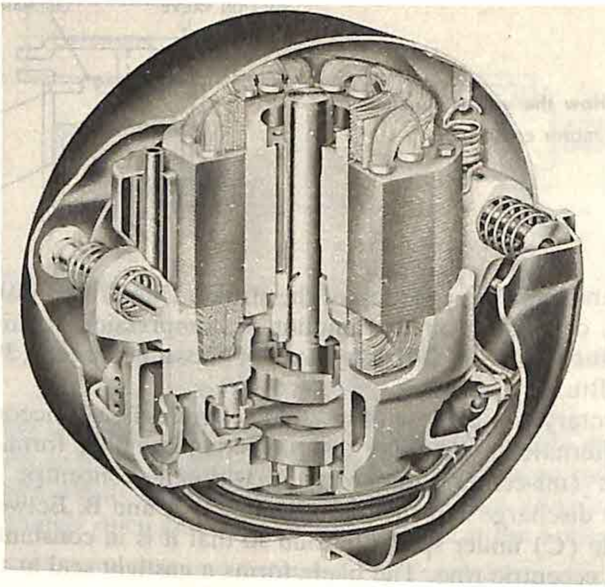


Fig. 2-4. Rotary compressor used in some low-pressure air-conditioner systems.



Courtesy Tecumseh Products Co.

Fig. 2-5. Internally-mounted hermetically-sealed "pancake" motor compressor.

Both the reciprocating-piston and the rotary compressors are driven by electric motors. In *open units*, the motor and compressor are mounted separately. Each has its own lubrication system, and a belt from the motor drives the compressor.

In *hermetically sealed* units, the compressor and motor are mounted within a welded steel housing and share a common drive shaft. Great care is taken during manufacture to keep out dirt and other foreign matter. Lubricant is added to the motor compressor at the time of manufacture, and further lubrication is not needed for the life of the compressor.

Most modern hermetically sealed compressors, or units as they are termed in the trade, are internally mounted (Fig. 2-5). This means the moving parts of the compressor are attached to the inside of the housing by springs, which absorb shock and vibrations. This type unit is commonly used in smaller window units of 5,000 to 15,000 Btu/hr.

In hermetically sealed units, the refrigerant vapor is introduced directly into the housing, from which it is drawn into an internal suction tube located above the surface of the lubricant or oil bath as shown in Fig. 2-6. The lubricating oil is free to splash into the internal suction tube and circulate with the refrigerant through the flow system, but in practice only an insignificant amount actually does find its way into the refrigerant flow.

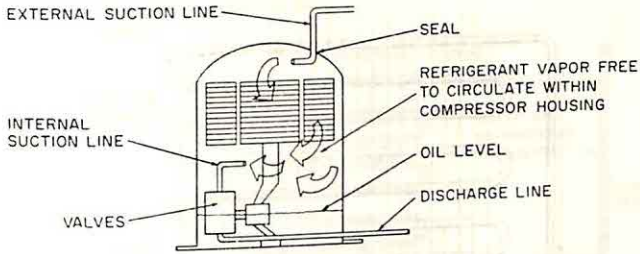


Fig. 2-6. Vapor flow in a hermetically-sealed motor compressor.

Evaporator

As we said before, if you set a tub of Freon or other refrigerant liquid in the center of a room and permit it to evaporate freely, you would have an air conditioner of sorts, although it would be woefully inefficient. Because the refrigerant is not confined, it would eventually evaporate, necessitating replacement. Such a system is obviously too crude and too expensive for practical use.

The evaporator in an air conditioner (or any refrigeration system) is just what its name implies—a chamber in which refrigerant liquids are permitted to evaporate, but the vapors are confined so the refrigerant may be used over and over. Fig. 2-7 shows a typical evaporator.

Evaporation of any liquid is accompanied by heat absorption from the surrounding air or objects. Thus, the evaporator takes heat from its surroundings and passes the heat to its refrigerant vapor, where it becomes the latent heat of vaporization.

The evaporator in any air-conditioning system precedes the motor compressor, in terms of the direction of flow of the refrigerant (see Fig. 2-1). There are two types in general use. In the *flooded* evaporator, the refrigerant is in both a liquid and a vaporized state. This type is rarely used in air conditioners.

The other type is the *dry* evaporator, in which the refrigerant is in a vaporized state throughout most of its travel. Evaporators are usually in the form of coils of tubing of exact length and inside diameter as shown in Fig. 2-7. Each turn of the copper tubing is called a "pass." The evaporators of typical room air conditioners may have 30 or 40 passes. In air conditioners the coils are nestled in a network of thin metal fins which, by enlarging the surface area, permit more efficient transfer of heat from the surrounding air to the coils.

The motor compressor, while running, tends to evacuate the inside of the evaporator. In this way the pressure inside the evaporator is kept at a predetermined and exactly balanced low.

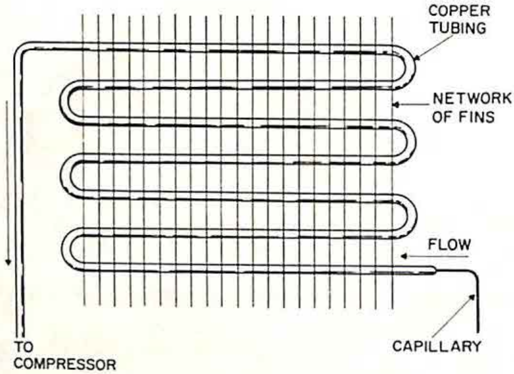


Fig. 2-7. Evaporator construction.

Remember that evaporators, or boilers as they are sometimes called, are identified with low pressure. Also, the function of the evaporator is to absorb heat from the surrounding air or objects, thus cooling them.

Condenser

The condenser (Fig. 2-8) performs just the opposite function from that of the evaporator—instead of absorbing heat from its surroundings, it gets rid of its heat to the surrounding air. Whereas the evaporator is located within the space to be cooled, the condenser is located on the outside so it can dissipate its heat without raising the temperature of the space. With respect to the flow of refrigerant, the condenser is located between the motor compressor and the capillary line. Thus, we say the condenser is on the *high side* of the system—meaning the high-pressure side, and the evaporator is on the *low side*. Air-cooled condensers such as the one shown in Fig. 2-8 are usually employed in room air conditioners.

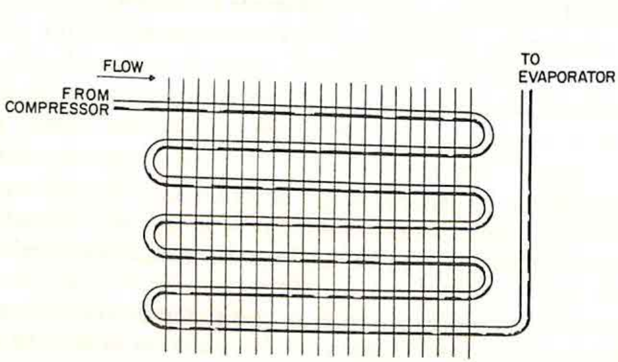


Fig. 2-8. Air-cooled condenser construction.

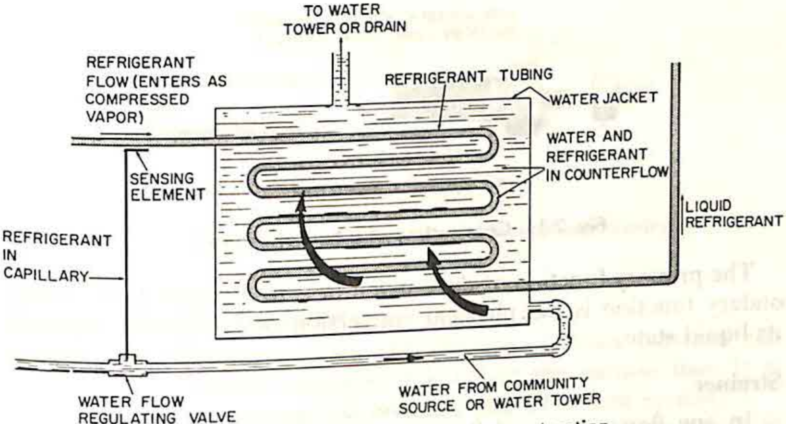


Fig. 2-9. Water-cooled condenser construction.

Large-capacity packaged units, and central systems, usually employ a water-cooled condenser. Water-cooled condensers are surrounded by a jacket containing water flowing in the opposite direction from the refrigerant, as shown in Fig. 2-9. Normal water pressure from the source will usually provide an adequate flow. However, in some central air-conditioning systems, an auxiliary pump is used to increase the flow and thereby provide greater heat transfer.

Most room air conditioners and many central systems use air-cooled condensers as shown in Fig. 2-10. Here, a fan directs a stream of air across the condenser coils and fins and expels the air to the outdoors. As we shall see later when we examine the air-flow system, air from the outdoors is mixed with condensate from the conditioned space and blown through the condenser to the outdoors. This assists in cooling the condenser.

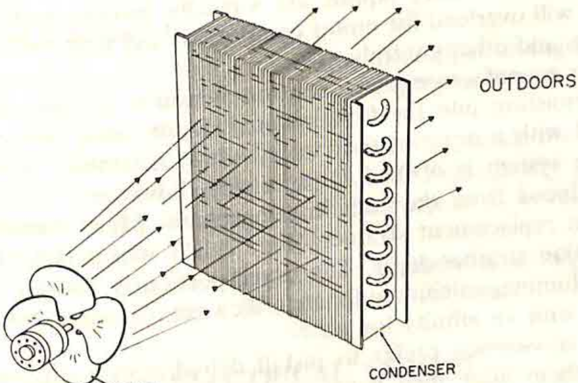


Fig. 2-10. Operation of an air-cooled condenser.

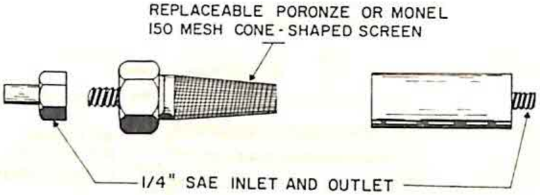


Fig. 2-11. Construction of a typical strainer.

The primary function of the condenser is to dissipate heat. A secondary function is the physical conversion of refrigerant vapor to its liquid state.

Strainer

In any flow system of liquids, all foreign matter must be kept out. This is particularly true in an air-conditioning system, where the inside diameter of some of the flow tubing is only a few hundredths of an inch.

A strainer (Fig. 2-11) serves to catch and hold particles of matter so that they cannot proceed through the system. It is usually a short length of copper tubing with a larger inside diameter than the rest of the tubing in the system and contains a fine cone-shaped mesh screen.

In large air-conditioning installations, most of the control valves also have strainers.

Dryer

Water will seriously impair the efficiency of a refrigerant flow system because it will not vaporize at the pressures and temperatures found in an air-conditioning system, but will pass through in a liquid state. Since liquids are virtually incompressible, their presence will overload the motor compressor and may even damage the valves and other controls.

During manufacture, rigid control measures prevent introduction of moisture into the flow system. Hence, most units are not equipped with a dryer at the factory—only a strainer is included. Once the system is opened for servicing, however, moisture may be introduced from the outside atmosphere. Most manufacturers provide a replacement strainer (Fig. 2-12) which is in reality a combination strainer-dryer. The dryer portion is packed with activated alumina, calcium sulphate, silica gel, or other dehydrating material with an affinity for water.

Some servicemen prefer to install dehydrators temporarily, removing them after they have accomplished their function so as not to disturb the balance of the system.

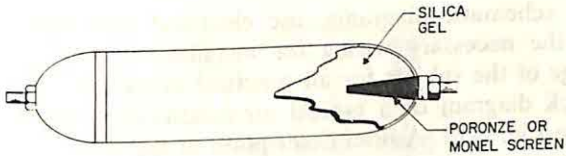


Fig. 2-12. Construction of a typical combination strainer-dryer.

Suction and Discharge Lines

The tubing through which the refrigerant flows between the evaporator and motor compressor is called the *suction line.* It is always identified with the low-pressure side of a flow system.

The tubing between the motor compressor and condenser is called the *discharge line.* It is always identified with the high side of the system.

Copper tubing is preferred for carrying the refrigerant between the compressor, condenser, and evaporator, because it can be bent without crimping and it is impervious to the corrosive effects of refrigerants.

Another reason for using copper tubing is the ease with which gastight joints may be made. The most common method of joining copper tubing to valves and other components is by a "sweated" joint, where liquid solder is flowed, by capillary action, into the recesses between the heated tubing and its fitting. As the solder cools and solidifies, a joint is formed from which no gas or liquid can escape.

Unsweating a joint involves heating it until the solder liquefies, then pulling the tubing and fitting apart.

Liquid and Capillary Lines

The *liquid line*, as its name implies, is the copper tubing in which the refrigerant is in a liquid state, under high pressure. It precedes the evaporator and follows the condenser.

A *capillary line*, part of the liquid line, has an inside diameter of only three or four hundredths of an inch. It immediately precedes the evaporator in the refrigerant flow. Its purpose is to restrict the flow of the refrigerant.

The control system was discussed in Chapter 1. It might be a good idea for you to review the controls at this time.

THE ELECTRICAL SYSTEM

The properties of electricity are discussed here only as they apply to some function or testing of an air-conditioning system. If you

can read schematic diagrams, use electrical test equipment, and perform the necessary wiring for installation, you have enough knowledge of the subject for all practical purposes.

A block diagram of a typical air-conditioner electrical system is given in Fig. 2-13. A brief description of the more common electrical components in an air conditioner follows. A more detailed description will be found in Chapter 3.

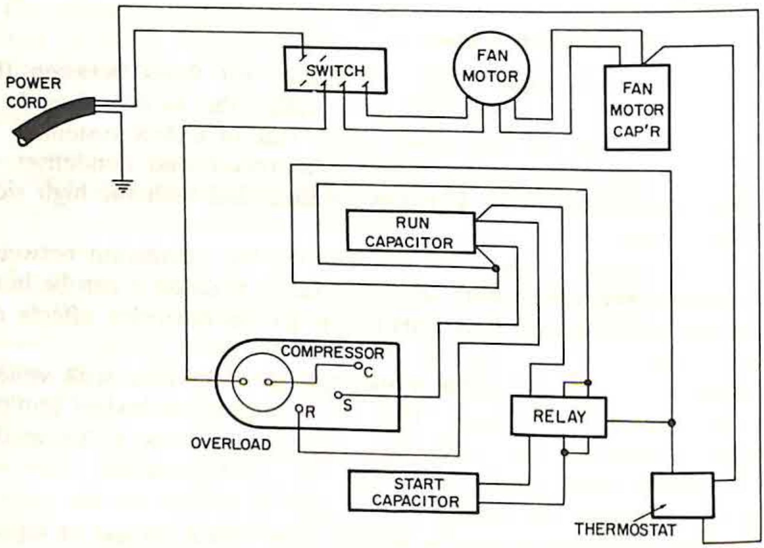


Fig. 2-13. Block diagram of the electrical system in a typical air conditioner.

Compressor and Fan Motors

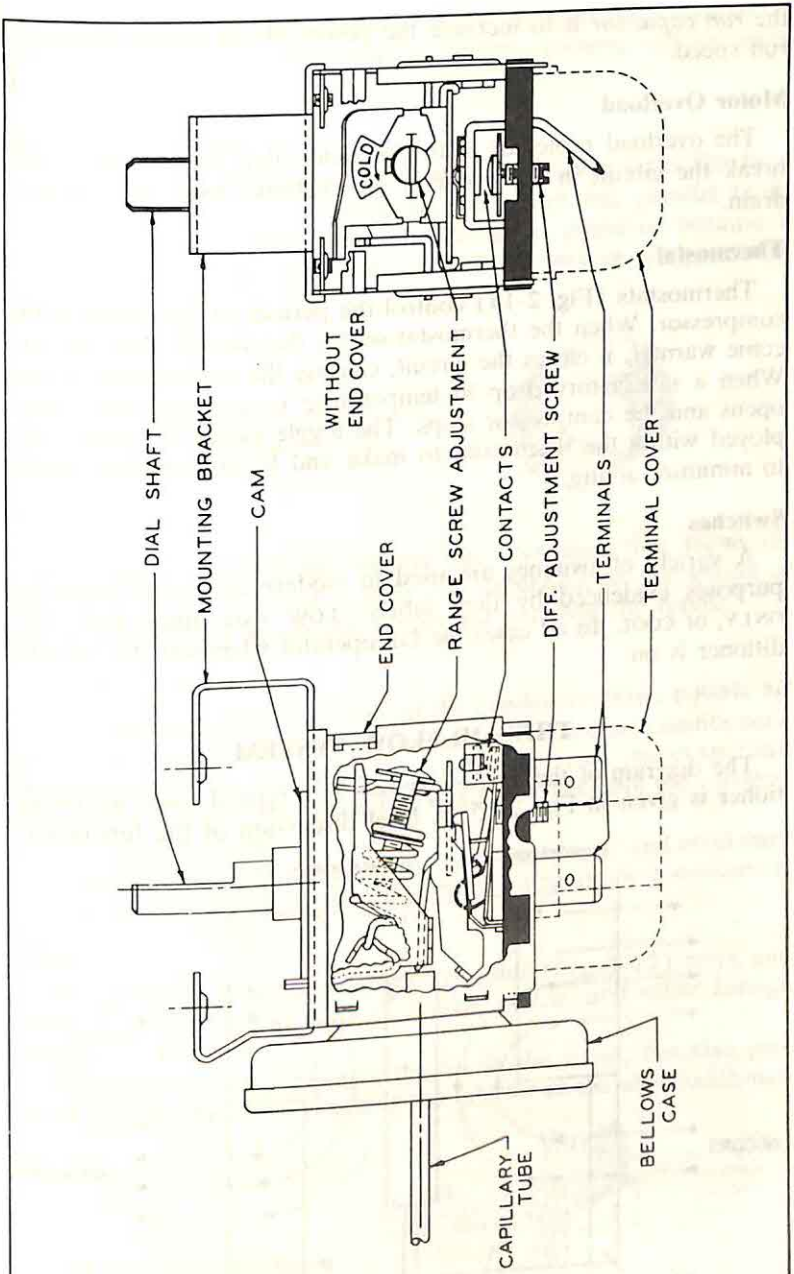
Air conditioners with hermetically sealed units have two induction motors. One is sealed inside the compressor housing and is coupled directly to the compressor. The other drives the condenser fan and evaporator blower (in most room air conditioners, only one blower is used for both purposes).

Relays

A relay is used in single-phase systems. It feeds current to a start winding in the compressor motor for approximately three seconds, then drops out of the circuit when the motor has attained its run speed.

Capacitors

Used in conjunction with a relay, a *start capacitor* increases the starting power (torque) of an induction motor. The function of



Courtesy Ranco, Inc.

Fig. 2-14. Construction of a typical thermostat.

the *run capacitor* is to increase the power of the motor during its run speed.

Motor Overload

The overload protector is an electrical safety device which will break the circuit in the event of an excessive load or a current drain.

Thermostat

Thermostats (Fig. 2-14) control the periods of operation of the compressor. When the thermostat senses that the air flow has become warmer, it closes the circuit, causing the compressor to run. When a satisfactory drop in temperature is achieved, the circuit opens and the compressor stops. The toggle switch is usually employed within the thermostat to make and break contacts cleanly to minimize arcing.

Switches

A variety of switches are used in modern air conditioners for purposes evidenced by their labels—LOW FAN, HIGH FAN, FAN ONLY, or COOL. In all cases the fan operates whenever the air conditioner is on.

THE AIR-FLOW SYSTEM

The diagram of the air-flow system in a typical room air conditioner is given in Fig. 2-15. A brief discussion of the function of

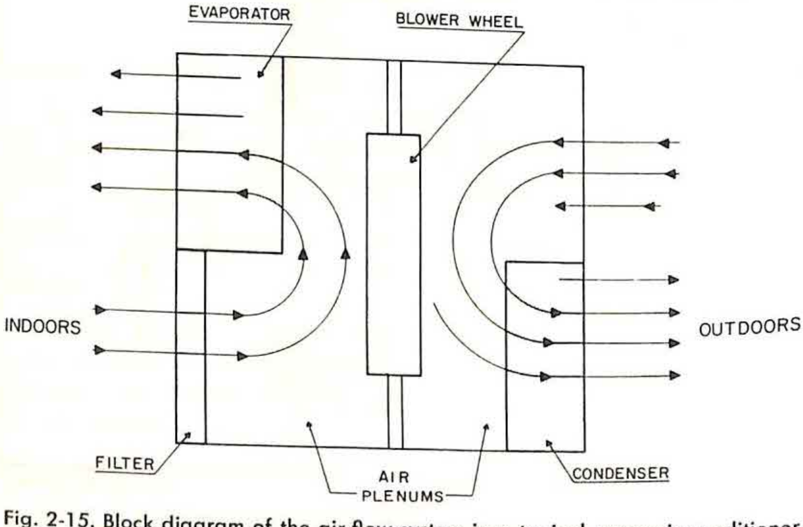


Fig. 2-15. Block diagram of the air-flow system in a typical room air conditioner.

the various components follows. More detailed explanations of the construction and operation of air-flow systems will be given later.

Evaporator Blower

In most air conditioners, the evaporator blower takes the form of a "squirrel cage," (a shortened drum with fins parallel to its axis) as shown in Fig. 2-16. This design is preferred because it is relatively quiet in operation, but still delivers an adequate volume of air.

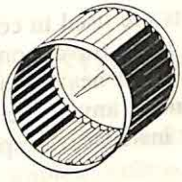


Fig. 2-16. Construction of a squirrel-cage blower wheel.

The blower, located just behind the evaporator fins, blows returned room air (or fresh outside air, depending on the setting of a selector switch) across the evaporator and into the room.

Condenser Fan

A ring-mounted fan just behind the condenser blows outside air across the condenser and back outdoors. In some air conditioners, the condenser fan also picks up condensate from the evaporator and blows it across the condenser fins to further cool the refrigerant in the condenser.

As mentioned earlier, both the evaporator blower and condenser fan are usually driven by the same motor in room air conditioners.

Filter

Placed in the return air stream, the filter (Fig. 2-17) traps and holds dust particles as well as smoke, pollen, and other foreign matter.

The filter not only cleanses the air in the room, but also prevents dirt and lint from reaching the interior of the air conditioner.

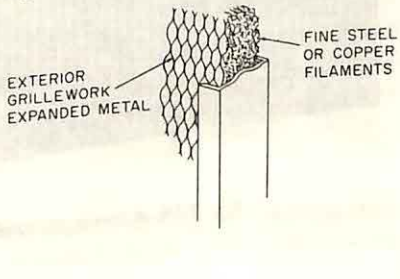


Fig. 2-17. Filter construction.

Dust on an evaporator or condenser may seriously impair the efficiency of either component.

There are two types of filters in general use. One is disposable; the other, a permanent type, can be washed, following the manufacturer's directions.

The function of collecting moisture from room air more properly belongs to the evaporator rather than the filter. The moisture condenses on the cold surfaces of the evaporator, and clean, dry air is returned to the room.

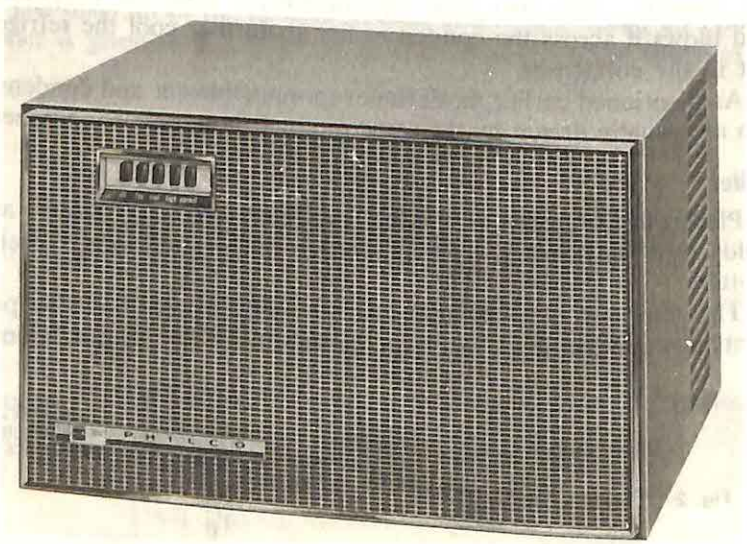
Air Ducts and Plenum

Air ducts are used in central air-conditioning systems, where the cooled air must travel some distance before being delivered. They are usually quite heavily insulated to keep heat out of their interiors.

A *plenum* is any space within an air conditioner where air must travel (for instance, the space between the blower and evaporator).

CABINETS, ACCESSORIES, AND KITS

The cabinet of a room air conditioner (Fig. 2-18) usually makes provision for directing or deflecting the air stream for greater convenience of room occupants. All controls are mounted on the front panel. It is usually designed for compactness, low silhouette, and sturdiness. This is particularly true for room air conditioners where part of the unit is exposed to the outdoors. Some are mounted on



Courtesy Philco Corp.

Fig. 2-18. A room air-conditioner cabinet.

the floor, beneath a window with air ducts leading to the outside.

Some air conditioners feature strip heaters, which supply auxiliary heat to the room on chilly days. Others provide a "reverse cycle" so that the air conditioner will work as a heater instead of a cooler.

Kits are usually supplied by the manufacturer to facilitate mounting the air conditioner in a casement window, through a wall, or in other situations. Usually included are filler panels, insulating strips, brackets, and other items necessary for a tightly fitted, securely mounted installation.

CENTRAL AIR-CONDITIONING SYSTEMS

The system just described is the common type of room air conditioner that is installed in a window or through the wall. We now turn our attention to more powerful and complex systems, the central air conditioners. These are multiroom systems ranging from 24,000 to millions of Btu/hour capacity. Systems employing air-cooled or water-cooled condensers may be used in either residential or commercial applications. Condensers may be self-contained, as in "packaged" units, or remotely located outdoors, as in air-cooled (waterless) air-conditioning systems. The scope of this book does not permit an exhaustive analysis of all the different systems in use. The following, however, are the more common types in use in the United States.

Add-on Cooling and Heating Systems

Add-on systems are used in conjunction with forced-air heating systems. They may be of the water-cooled condenser type, using noncirculated community water supplies where water is plentiful, or recirculating water in an outdoor water tower, where the use of water for air conditioning is restricted by the community.

Add-on systems also employ remotely located air-cooled condenser-compressor units. These are installed in a breezeway, on the roof, or any other place where the heat extracted from the interior can be expelled to the atmosphere.

An evaporator unit is located on top of the forced-air furnace, the blower of which performs the double function of circulating warm air in winter and cooled air in summer. If head room is limited, an evaporator-blower may be located elsewhere in the ductwork, or several such units may be installed at strategic places.

Fan Cooling-Unit Systems

For homes with steam or hot-water heating, a "cooling-only" air-conditioning system may be installed. Such units employ a con-

denser-compressor unit outdoors and an evaporator-blower in the ceiling or attic. Appropriate ductwork leads from the evaporator-blower to the cool-air registers.

A variation of this system employs the compressor indoors, and the condensing unit and blower outdoors.

Packaged Units

These completely self-contained units are water- or air-cooled, with internal components arranged either horizontally or vertically.

Water-cooled packaged units are especially designed to economize on "make-up" water. They do this by using virtually the same water over and over. An outdoor water tower dissipates the heat of the water to the atmosphere.

Air-cooled packaged units require ductwork to the outdoors, to expel warm air from the condenser coils.

Large-Capacity Commercial Systems

For multiroom hotels and office buildings, large-capacity centrifugal compressors and water-cooled condensers are used. Low-pressure refrigerant is employed, to minimize refrigerant leak and purging problems.

The delivery of large quantities of cooled air to widely separated rooms presents several problems. Because of the distance traveled, the air absorbs some heat. Also, such delivery is difficult to regulate for individual comfort. For these reasons, most modern large-capacity systems employ different means of distributing conditioned air.

In a typical modern system, a central ventilation system delivers cooled and dehumidified, or warmed and humidified, air to each room through a system of ducts. These ducts, which are much smaller than for a system delivering conditioned air exclusively, permit greater efficiency and more uniformity in delivery.

In addition, a small motor-driven cooling or heating unit is located in each room. Cooled water is delivered to this unit in the summer and warmed water in winter. A self-contained fan recirculates the air in the room.

The main functions of the central system are to provide the proper humidity in the room without affecting the degree of temperature desired by the occupants, and to deliver fresh, filtered air. The functions of the room unit are to raise or lower the temperature in the room as desired by the occupant, and to filter the recirculated air.

Thus, a building manager may regulate the ventilation and humidity for all rooms, depending on the weather. At the same time, chilled water (50 degrees F) is delivered to each room in summer,

and warmed water (90 degrees F to 140 degrees F) in winter. The occupant regulates the rate of flow of the water; thus, he has direct control over the temperature in the room.

The air delivered through the central ventilation system is at or near the desired room temperature—60 degrees F to 70 degrees F in summer, 80 degrees F to 85 degrees F in winter.

The compressors in large commercial systems have capacities ranging from fifty to thousands of tons. Their principal function is to chill water, although they may also warm water in heat-pump applications, wherein the operation of the refrigeration cycle is reversed. Otherwise, the principle of operation is the same for large-capacity central systems as it is for room air conditioners.

Residential Central Systems

There is an important difference between residential central air-conditioning systems and room or auto systems, besides the obvious one of capacity. This difference lies in the *balance* of the system. In room air conditioners, the operator or installer has only a limited range of adjustments possible; and these adjustments are mainly for the length of time the compressor is running and the frequency of the running cycles. The system of the room air conditioner is prebalanced—that is, the amount of refrigerant in the system, the pressures generated by the compressor, and even the rate of flow of the refrigerant, the amount of superheated vapor in the evaporator, and the rate of flow of the cooling air around the condenser are all predetermined at the factory, with no adjustments possible.

Any radical change in flow rate, size of tubing, amount of refrigerant, etc., tends to throw the room air-conditioner system out of balance, causing a loss of efficiency or downright failure. Central air-conditioning systems, on the other hand, allow for adjustments at several places to meet varying conditions.

WATER-COOLED CENTRAL SYSTEMS

To understand the differences between room air conditioners and a typical central system, let us now examine a central air conditioner employing a water-cooled condenser.

As we said before, adjustments are provided at several places to meet the varying conditions in central air-conditioning systems. (This is not to say that the systems are not balanced when they leave the factory.) The range of adjustments in a water-cooled central air-conditioning system is necessary mainly because water is used for cooling the hot vapors in the condenser.

Many communities restrict the use of water for air conditioning. In addition, water in large amounts is expensive in most communi-

ties in the United States. Ideally, water from the community source, at low ground temperatures, is best for cooling because it can absorb far more sensible heat per cubic volume.

However, local restrictions sometimes make it necessary to construct a water tower (Fig. 2-19) so that the same water can be used over and over. Here, a certain amount of make-up water must be introduced into the system to replace the evaporated water.

The water from a tower surrounded by summer air is a lot warmer than water from under the ground. As a result, the heat-transfer efficiency of the condenser may be severely restricted. This may require adjustments in the refrigerant flow rate, the range of pressures in the system, and even the volume of refrigerant in the line.

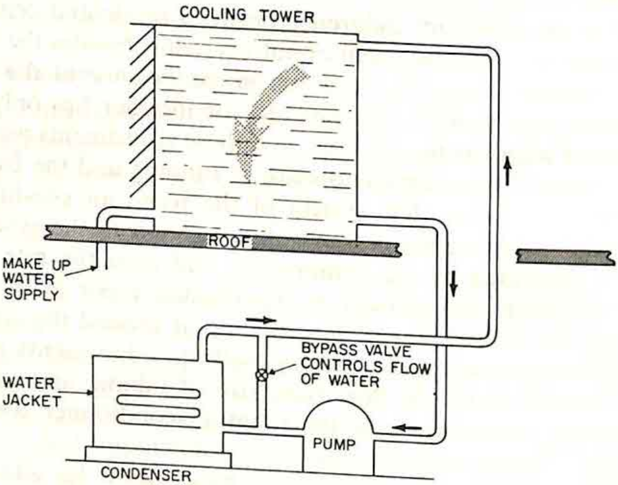
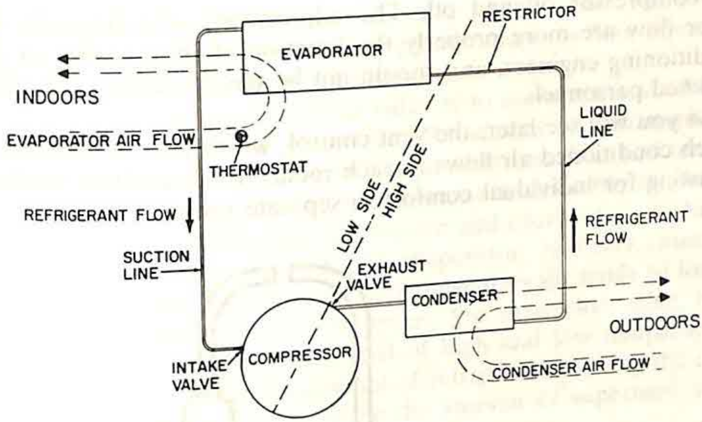


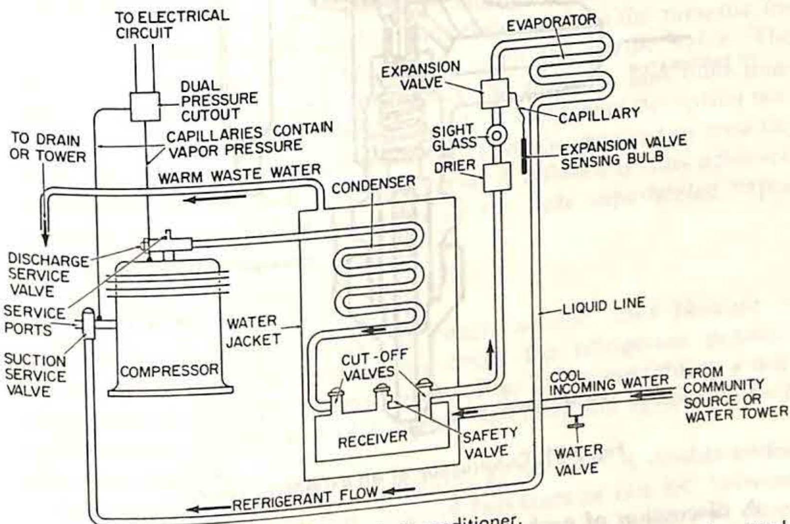
Fig. 2-19. A water tower permits re-use of the same water to cool the condenser of large central air-conditioning systems.

A central air-conditioning system employs components not normally found in room air conditioners. In the simplified diagrams of Fig. 2-20, you can compare the differences between the room air conditioner in Fig. 2-20A and a typical central air-conditioning system in Fig. 2-20B.

The central system unit includes the following *new* components: Just ahead of the evaporator is an *expansion valve* connected to a sensing bulb and capillary tube. At the compressor are a *suction service valve* and a *discharge service valve*. Also connected to the compressor is the *dual-pressure cutout* control. Below the condenser, in terms of refrigerant flow, we find a *receiver* connected by *cutoff valves*. A *safety valve* is also mounted on the receiver.



(A) Room air conditioner.



(B) Central air conditioner.

Fig. 2-20. Difference in components of typical room air conditioner and central air-conditioning system.

Finally, between the condenser and expansion valve are found a *dryer* and a *sight glass.*

These controls are placed in the line, not to cycle the compressor on and off as in room air conditioners, but to restrict and control the flow of refrigerant, charge or evacuate the system, and control the flow of cooling water in the condenser. Central systems still employ a thermostat switch with which the operator or user can cycle

the compressor on and off. The adjustments of refrigerant and water flow are more properly the function of the installer or air-conditioning engineer, and should not be tampered with except by qualified personnel.

As you will see later, the vent control, which governs the rate at which conditioned air flows to each room, is still another means of adjusting for individual comfort in separate rooms.

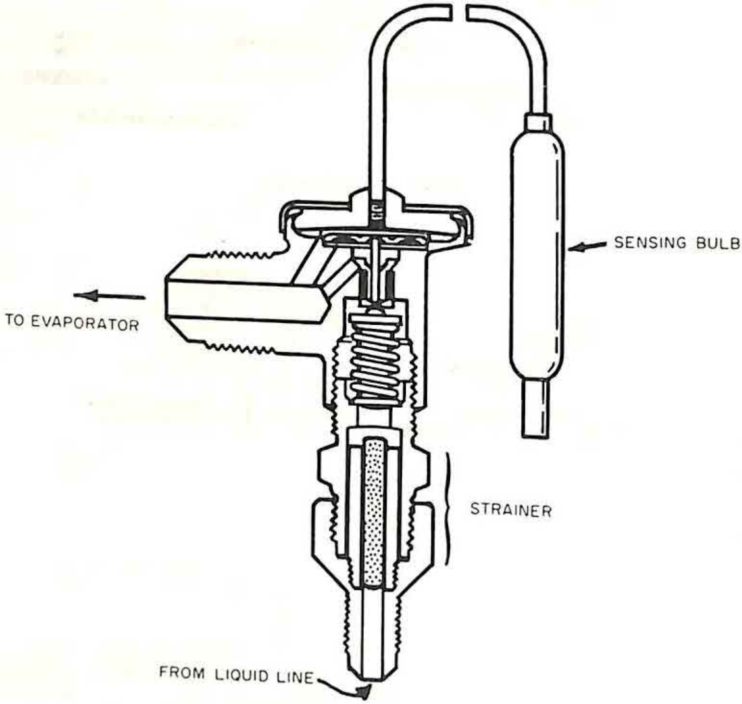


Fig. 2-21. Construction of an expansion valve.

A discussion of each of the new components will aid in understanding the principles and operation of a central air-conditioning system.

Expansion Valve

The expansion valve serves the same purpose as the restrictor tubing in a room air conditioner, with one important difference—it is adjustable.

In principle, the expansion valve (Fig. 2-21) works exactly like the thermostatic control which cycles the compressor on and off, except that in the expansion valve, the contracting and expanding

bellows or diaphragm opens or closes a needle valve (instead of triggering an electrical switch) to permit more or less liquid refrigerant to flow into the evaporator.

The purpose of the expansion valve is to control the amount of superheated vapor in the evaporator. Remember we discussed earlier that some superheated vapor (vapor that has absorbed sensible heat above the latent heat of evaporation) is desirable to prevent any liquid from reaching the compressor and overloading it. An excess of superheated vapor in the evaporator, however, means a lower cooling efficiency because superheated vapor tends to lose its sensible heat back to the cooled space. The expansion valve, being preset within a suitable differential of high and low temperatures, automatically regulates the amount of refrigerant entering the evaporator, thus effectively controlling the amount of superheat in the evaporator.

The expansion valve is adjusted by altering the tension of the spring which tends to hold the valve closed. When the temperature of the evaporator at the sensing bulb rises, so does the pressure inside the expansion valve, tending to open the needle valve. The greater the spring tension, the higher the pressure and bulb temperature required to open the valve. Thus, increasing the spring tension increases the amount of superheated vapor required to raise the temperature of the bulb, and vice versa. A balance is thus achieved between the extremes of too much or too little superheated vapor in the evaporator.

Service Valves

Service valves are required in central-system units because of the need to evacuate, charge, or check the refrigerant pressure from time to time. Three-way valves (Fig. 2-22) containing a normally closed service port (C) permit servicing the system without loss of refrigerant.

A typical three-way valve functions as follows: A double-ended needle can be seated against either of two seats or else left between them. In the normally open position (Fig. 2-22A), there is unrestricted flow between A and B, and no flow at C. In the cracked position (Fig. 2-22B), there is unrestricted flow between A and B, but enough vapor is allowed into C so that the pressure at the port is equal to that in the line. In Fig. 2-22C, there is unrestricted flow between A and C, but no flow between A and B.

To read the pressure or suction in the line, remove the plug at C and attach a compound gauge. Now *crack* the valve by opening it about one-quarter turn, or until the needle on the gauge begins to rise. Never open the valve too fast or too much; the surge of pressure may damage the gauge.

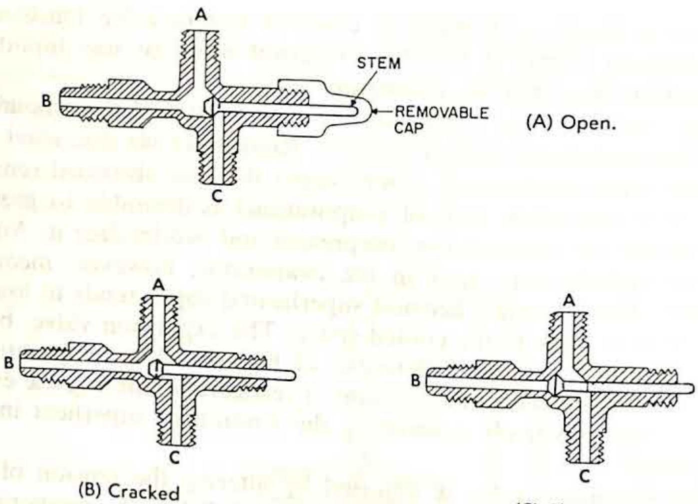


Fig. 2-22. Cross-sectional views of a service valve in the three possible positions.

In central-system units, service valves are found in both the suction and discharge lines. Usually they are connected adjacent to the compressor or, in discharge service valves, to the manifold or compressor head.

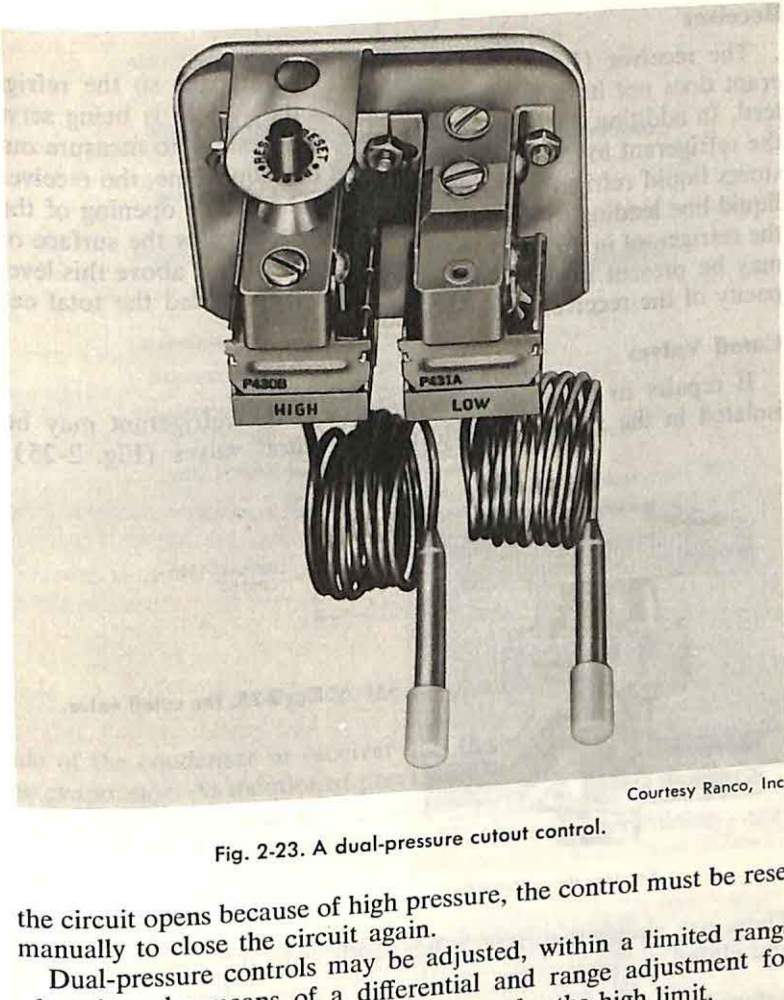
When the compressor must run during service, the refrigerant flow must never be completely restricted by closing the service valves all the way, or dangerous head pressures will result.

Dual-Pressure Cutout

The dual-pressure cutout (Fig. 2-23) is a pressure safety device found on units of 24,000 Btu/hr or higher. It is made necessary by the possibility of human error inherent in a central system. The cutout is introduced into the refrigerant line as close to the compressor as possible, with one capillary in the suction line and the other in the discharge line. Low pressure, between 20″ vacuum and 50 psia, is introduced into the low side of the control, which is set to cut out at a predetermined low and to cut in when the minimum low pressure is restored.

The discharge capillary introduces high pressure, from 100 to 240 psia, into the high side of the control, which is set to cut out at a predetermined high.

Spring-loaded bellows expand and contract with these changes in pressure and, in doing so, trigger a switch in the electrical circuit of the system. If the head pressure exceeds the high-limit setting on the dial, or if the suction pressure falls below the low-limit setting, the switch opens the circuit and stops the compressor. When



Courtesy Ranco, Inc.

Fig. 2-23. A dual-pressure cutout control.

the circuit opens because of high pressure, the control must be reset manually to close the circuit again.

Dual-pressure controls may be adjusted, within a limited range of settings, by means of a differential and range adjustment for the low ranges and by a single adjustment for the high limit.

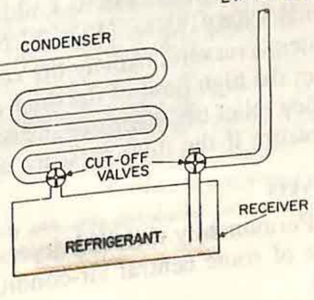


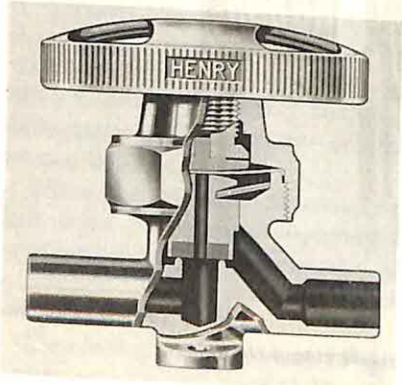
Fig. 2-24. The receiver which holds a reserve supply of liquid refrigerant.

Receiver

The receiver (Fig. 2-24) provides storage space so the refrigerant does not have to be drained while the system is being serviced. In addition, the receiver makes it unnecessary to measure out the refrigerant to the ounce. Located in the liquid line, the receiver stores liquid refrigerant under pressure. The intake opening of the liquid line leading to the evaporator is located below the surface of the refrigerant in the receiver. Thus, any refrigerant above this level may be present in the system as a reserve, provided the total capacity of the receiver is not exceeded.

Cutoff Valves

If repairs to the system are necessary, the refrigerant may be isolated in the receiver by closing the cutoff valves (Fig. 2-25).



Courtesy Henry Valve Co.

Fig. 2-25. The cutoff valve.

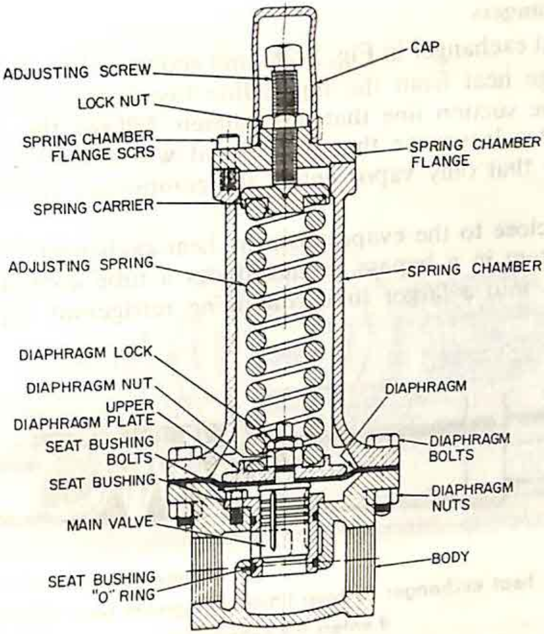
These are simple two-way valves with only two positions, open and closed.

Safety Valve

To prevent excessive buildup of pressure in the line, an additional safety valve (Fig. 2-26) is located at the point of highest system pressure, namely the receiver. This valve, which is set higher than the high limit of the dual-pressure cutout, is designed for emergency relief of dangerous pressures. It also serves as a backup safety measure if the dual-pressure cutout control fails.

Dryers

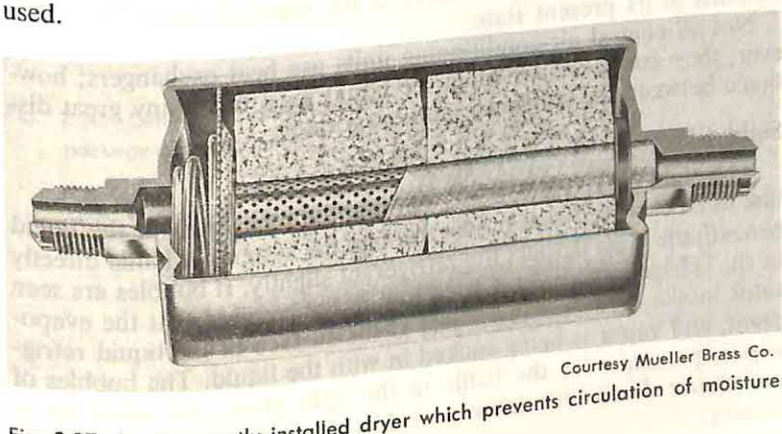
Permanently installed dryers (Fig. 2-27) are located in the liquid line of some central air-conditioning systems, one at the discharge



Courtesy Atlas Valve Co.

Fig. 2-26. The safety valve.

side of the condenser or receiver and the other at the entrance to the evaporator. As mentioned previously, dryers are necessary after repairs have been made to the system, to strain out any traces of moisture in the line. Two types—refillable and nonrefillable—are used.



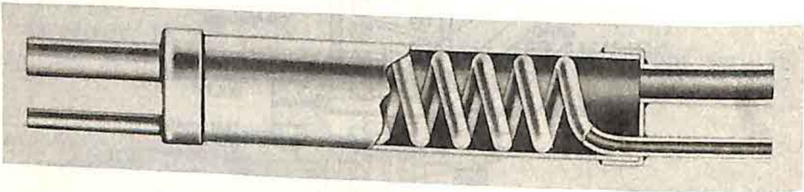
Courtesy Mueller Brass Co.

Fig. 2-27. A permanently installed dryer which prevents circulation of moisture in the lines.

Heat Exchangers

The heat exchanger in Fig. 2-28 (not shown in Fig. 2-20) is used to exchange heat from the liquid line just before the expansion valve to the suction line that immediately follows the evaporator. This is extra insurance that only liquid will enter the expansion valve, and that only vapor enters the compressor from the evaporator.

Placed close to the evaporator, the heat exchanger is connected to the system in a bypass. It introduces a tube containing liquid refrigerant into a larger tube containing refrigerant vapor traveling in the opposite direction. In some exchangers, the inner tube contains the vapor and the outer tube the liquid; in still others, the liquid travels through a coil.



Courtesy Superior Valve and Fittings Co.

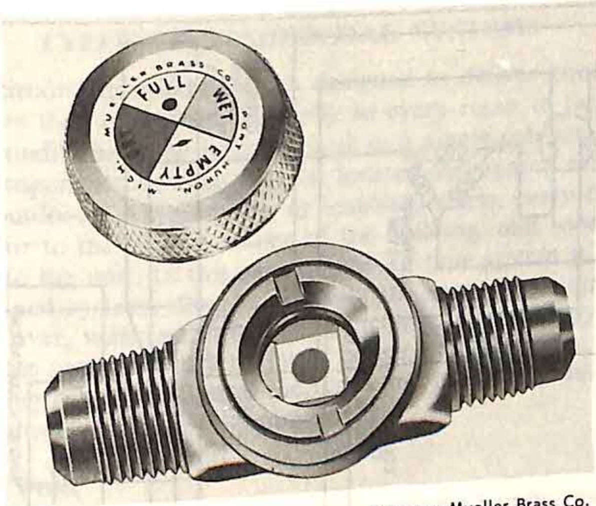
Fig. 2-28. A heat exchanger to keep liquid refrigerant from vaporizing before it enters the evaporator.

As mentioned previously, heat passes from a substance of higher temperature to one of lower temperature. The warm liquid surrenders more of its sensible heat to the cooler vapor, lowering the heat of the liquid and raising the heat of the vapor to assure that each remains in its present state.

Not all central air-conditioning units use heat exchangers; however, they are necessary when the liquid must travel any great distance between the condenser and evaporator.

Sight Glass

The sight glass (Fig. 2-29) permits the refrigerant in the liquid line to be observed as it passes through the system. A baffle directly beneath the glass detours the refrigerant slightly. If bubbles are seen in the refrigerant, its level is so low in the receiver that the evaporator intake-tube opening is just at the surface of the liquid refrigerant, and vapor is being sucked in with the liquid. The bubbles of vapor, passing over the baffle in the sight glass, will show up as turbulence. If no turbulence is visible, the refrigerant level is satisfactory.



Courtesy Mueller Brass Co.

Fig. 2-29. The sight glass which permits visual observation of liquid refrigerant.

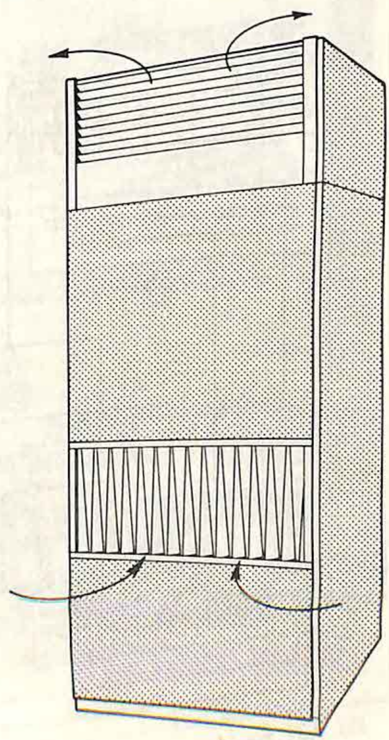


Fig. 2-30. Central air-conditioning package-unit installation.

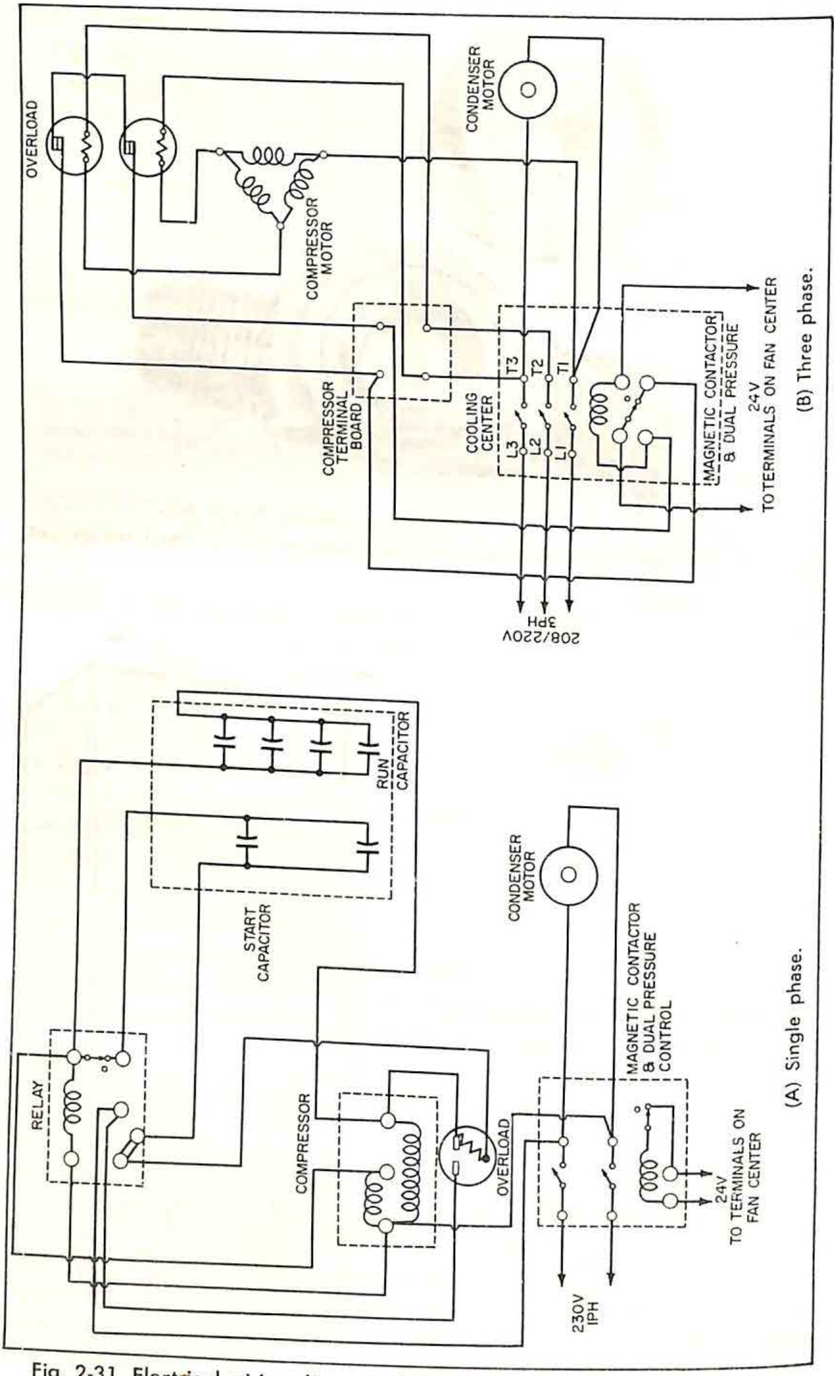


Fig. 2-31. Electrical wiring diagrams for single-phase and three-phase units.

TYPES OF RESIDENTIAL SYSTEMS

A multiroom air conditioner is designed to deliver conditioned air to more than one room, normally to every room in the house. The air conditioner may be contained in a single cabinet housing all the components, or they may be located throughout the home, or even outdoors. Air plenums, or insulated ducts, carry the conditioned air to the various rooms of the building, and room air is led back to the unit. In this respect, the air-flow system is considered a closed system—that is, virtually the same air is circulated over and over, with fresh air coming in through the many cracks and crevices present in any normally constructed building.

Following is a discussion of the types and modifications of residential central systems in common use.

Packaged Units

Also known as free-standing or self-contained units, packaged units are designed with capacities of 24,000 to 90,000 Btu/hr, a

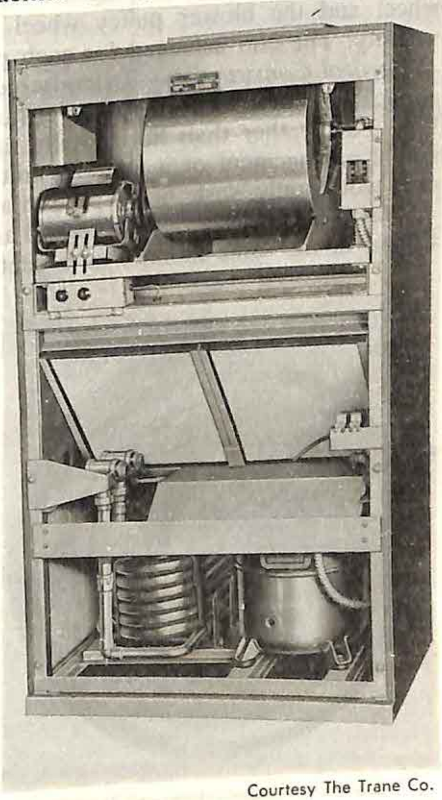
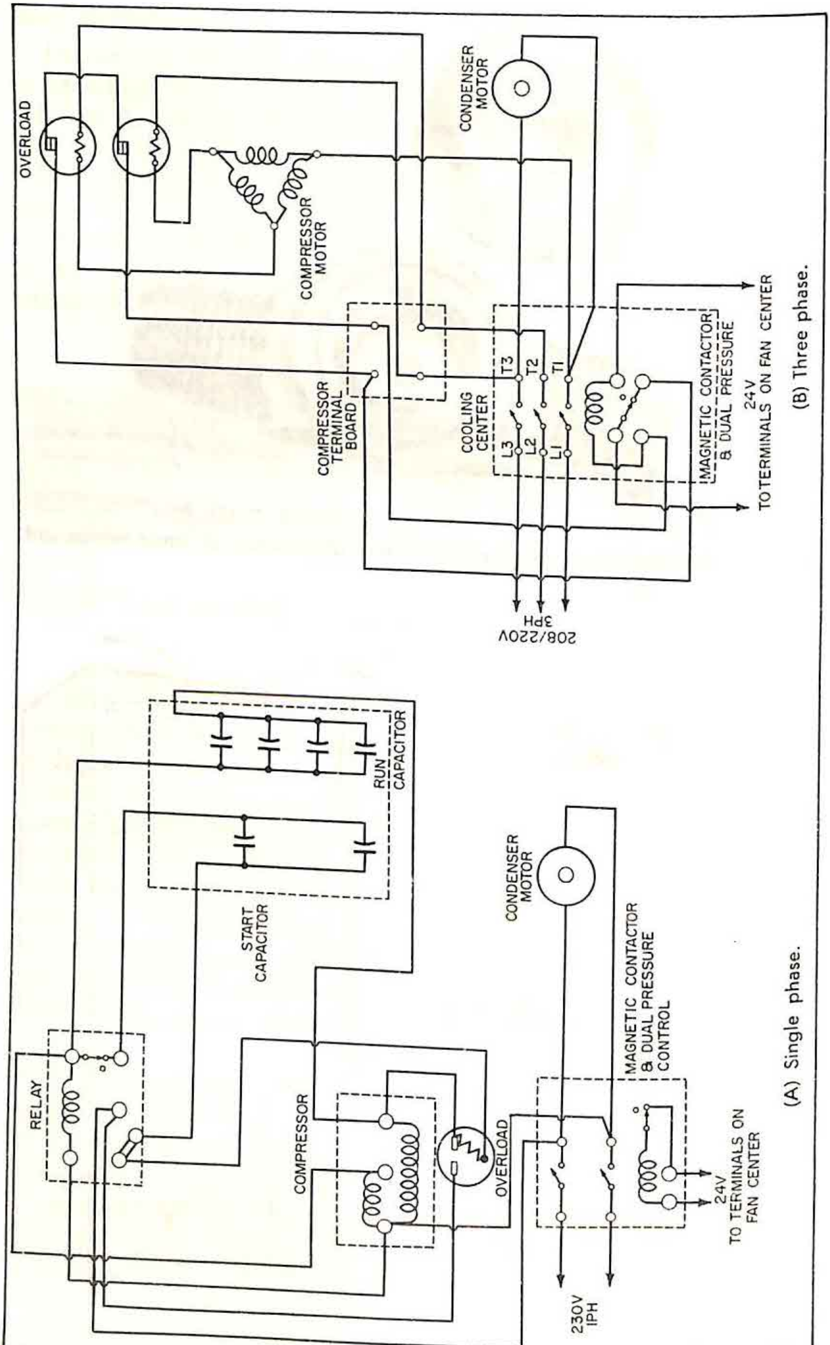


Fig. 2-32. Interior view of typical central air-conditioning unit.

Courtesy The Trane Co.



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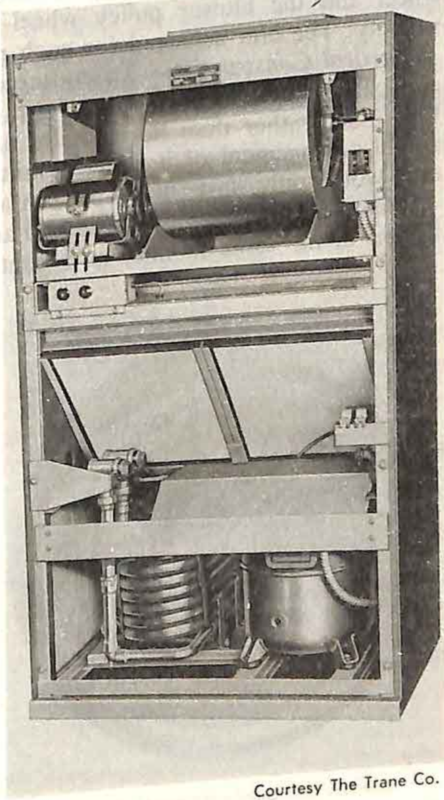


Fig. 2-32. Interior view of typical central air-conditioning unit.

Courtesy The Trane Co.

range sufficient for most homes and small office buildings and stores. They are made in both water- and air-cooled models.

A typical packaged unit (Fig. 2-30) contains all or most of the components examined previously. It is mounted in an attractive cabinet designed to cushion both noise and vibration. Water-cooled units are approved for closet installation—that is, they have been designed to eliminate possible fire hazard, even when installed in a confining space.

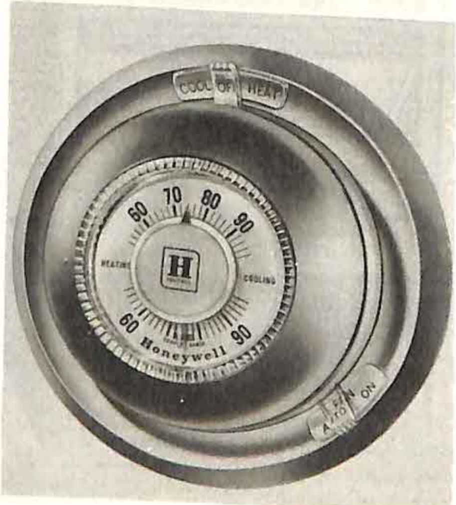
Packaged units are designed for either single-or three-phase operation. Three-phase operation requires special electrical power supplies not normally available to homes or small office buildings. Electrical wiring diagrams for both single- and three-phase models are given in Fig. 2-31.

Other differences between packaged and room units, besides those already discussed, are as follows:

Belt-driven Blower Wheel—Because of the greater air flow required, power for the fan or blower is supplied by a belt drive. Provision is made for varying the ratio between the motor drive wheel and the blower pulley wheel for greater or less air-flow velocity. The cfm achieved for each position is normally marked.

Vertical Construction—To conserve floor space, components in a packaged unit are most often arranged vertically as shown in Fig. 2-32, rather than horizontally like window units. The horizontal arrangement of a window unit, required for a low silhouette, would only waste floor space in a packaged unit.

Thermostatic Controls—A central air-conditioning system is controlled in the same manner as a central heating system. A room



Courtesy Minneapolis-Honeywell Regulator Co.

Fig. 2-33. A dual-control thermostat for regulating heat in winter and cooling in summer.

thermostat at a single location in the building controls the on and off cycling of the compressor, or restricts or permits the flow of refrigerant into the evaporator. The thermostat location is determined in the same manner as for a heater thermostat—i.e., any spot subject to extremes of hot or cold must be avoided.

Where central air-conditioning systems are used in conjunction with forced-air heating systems, a heating-cooling thermostat (Fig. 2-33) is employed.

Waterless Central Units

In areas where water for cooling is at a premium, the waterless central air-conditioning system (Fig. 2-34) provides a practical solution. The condenser is located outside the building, in a shaded area exposed to the prevailing summertime winds. Compressed refrigerant vapor is circulated to the condenser by the compressor, which may be located indoors or may be an integral part of the condensing unit. Outside air, introduced around the condenser coils, carries off the heat in the compressed vapor, causing the latter to condense into liquid. The liquid refrigerant then flows into the interior of the building, where it enters the evaporator-blower and absorbs heat from the recirculated inside air.

A typical condensing unit containing the compressor is shown in Fig. 2-35. These sturdy units are designed to withstand long

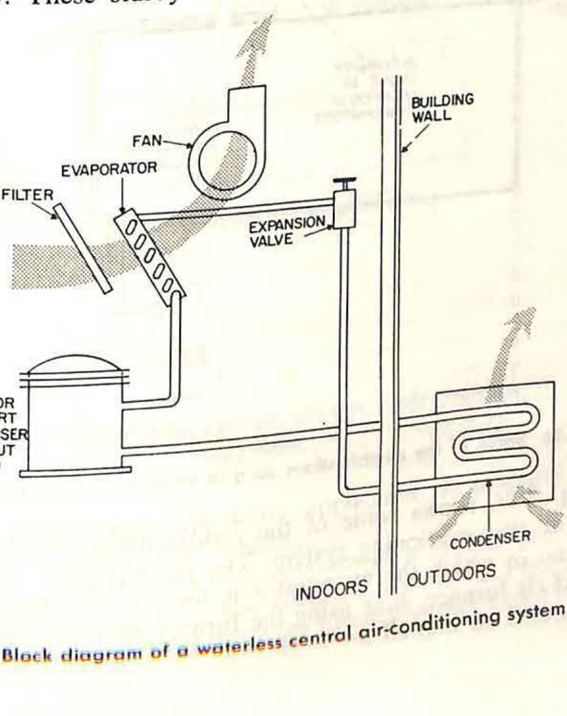
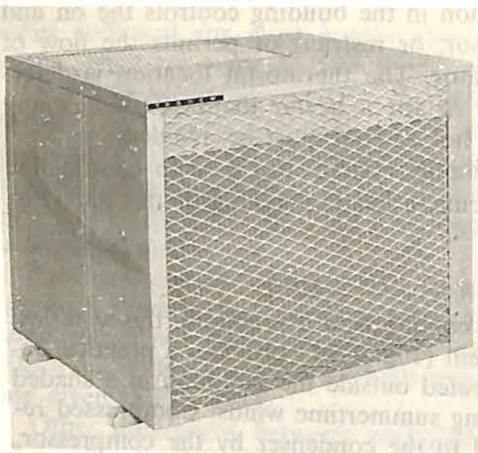


Fig. 2-34. Block diagram of a waterless central air-conditioning system.



Courtesy The Trane Co.

Fig. 2-35. Condensing unit used in waterless central system.

years of service outdoors. Fresh outdoor air is drawn into the cabinet and then expelled back outdoors after passing over the condensing coils.

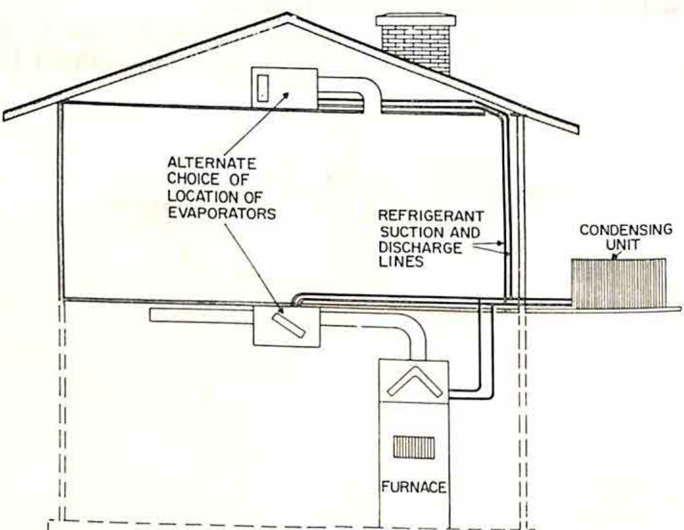


Fig. 2-36. Some of the combinations used in waterless air-conditioning systems.

Fig. 2-36 shows some of the combinations possible with this type of air-conditioning system. The most popular application is the one in which the evaporator is located in a bonnet above a forced-air furnace, thus using the furnace blower system to circulate cooled air into all rooms through existing ductwork.

Where headroom above the furnace is limited, evaporators may be installed in a main duct at the ceiling, still using the furnace blower for circulation. Or an evaporator-blower unit may be installed in an attic, with short ducts leading to the ceilings of the

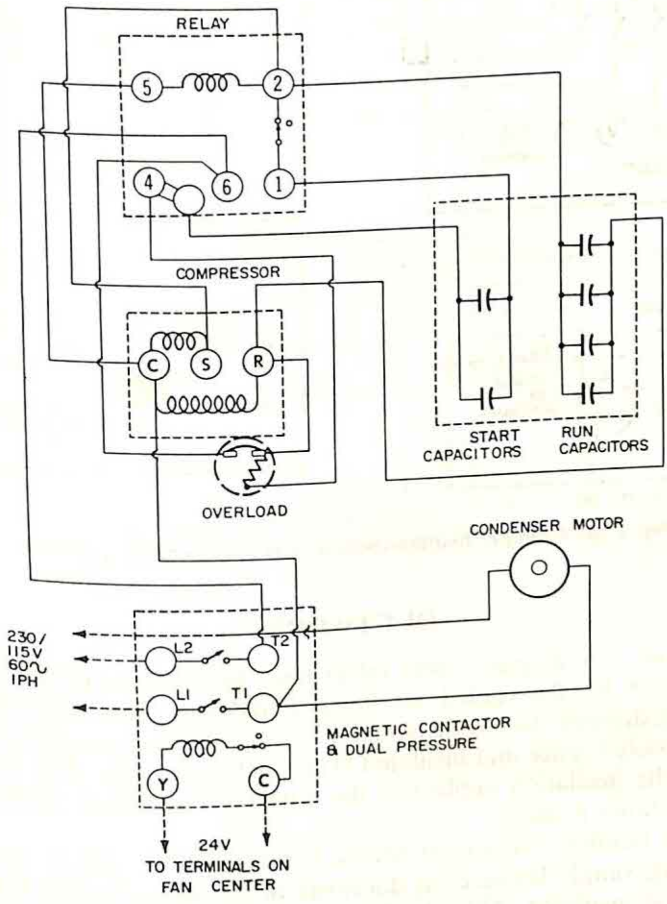


Fig. 2-37. Wiring diagram for 230-volt, 60-hertz, single-phase system (cooling only).

rooms to be conditioned. The latter application is practical for homes without a heating duct system.

Fig. 2-37 is an electrical wiring diagram of a typical waterless remote air-conditioning unit. The diagram shown in Fig. 2-38 traces the circuitry of a system using the furnace blower and a heating-cooling thermostat.

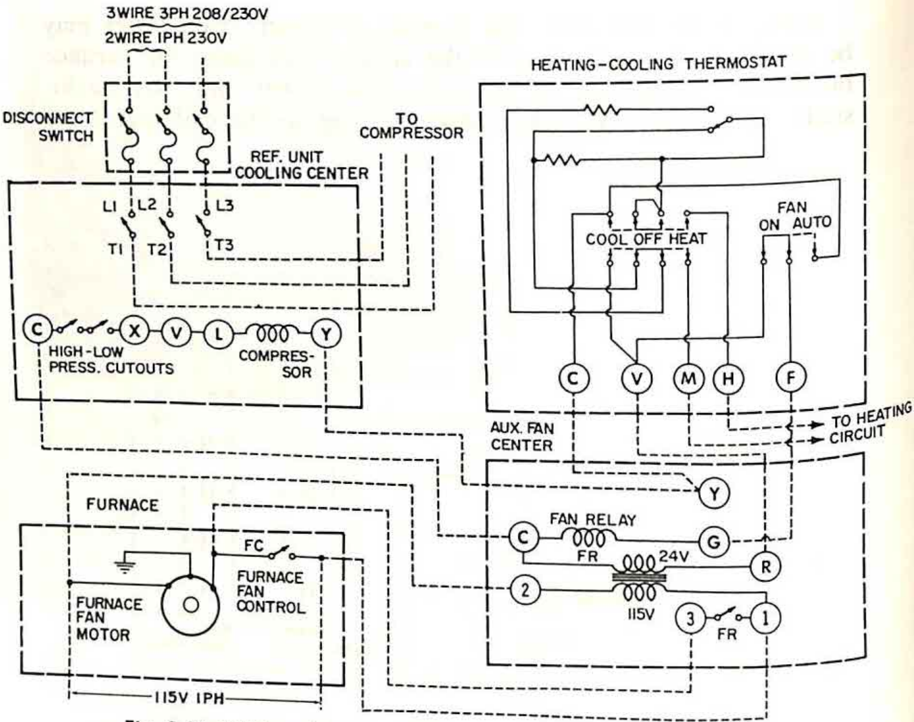


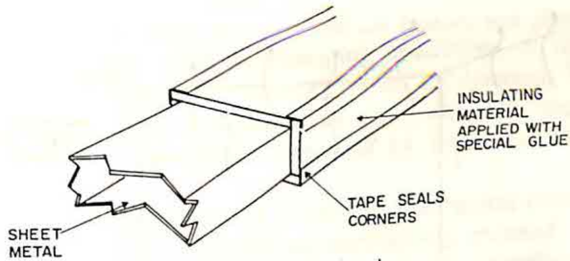
Fig. 2-38. Wiring of heating-cooling system using furnace blower.

DUCTWORK

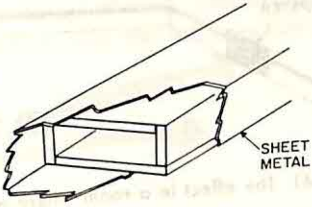
As you can imagine, every effort must be made to prevent heat absorption by the cooled air being circulated. This requirement means extensive ductwork planned for the shortest possible travel to the cooled space and insulated every inch of the way. Fig. 2-39A shows the insulation applied to the outside of the duct, while Fig. 2-39B shows it inside.

Some builders claim their homes are suitable for central air conditioning, simply because the ductwork of the forced hot-air heating system is insulated. This can be accepted as valid—with reservations. In heating systems, the air is spilled into the room as near the floor as possible. Since warm air rises, it creates a slight current which effectively circulates the warm air to all parts of the room, as shown in Fig. 2-40. The air is returned to the furnace through a register also located on or close to the floor and across the room from the warm-air register.

If the same ductwork were used for air conditioning, the cooled air would only travel across the floor, never rising very high, and enter the return register on the other side of the room, as shown



(A) Outside insulated.



(B) Inside insulated.

Fig. 2-39. Cross section of insulated duct.

in Fig. 2-41. Such a system obviously would not provide satisfactory cooling.

The best location for cool-air vents into the room is in the ceiling, as shown in Fig. 2-42. The cooled air will then tend to sink to the floor, creating currents and thereby providing uniform circulation. It is possible to modify existing ductwork in a home, but every turn or bend of the duct slows down the air flow.

Cool-air and return-air ducts should be kept separated in their paths around the building, or the space between them kept heavily insulated if they must be run parallel to each other.

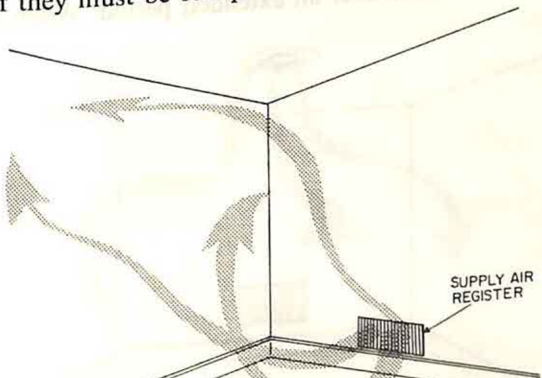


Fig. 2-40. Warm air rises from heat registers, normally located close to floor.

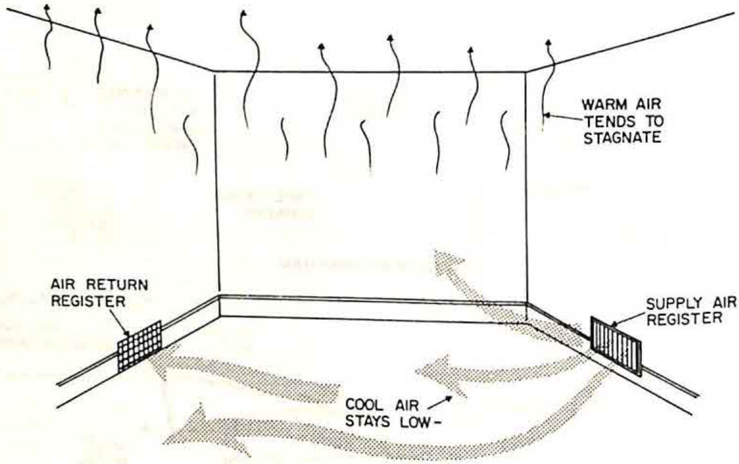


Fig. 2-41. The effect in a room where warm-air registers deliver cooled air.

In every building, one or more rooms will demand a greater supply of cool air than others, because of large windows, rooms under roofs, and larger rooms. The more obvious trouble spots can be singled out even before the installation is designed, and larger ducts can be installed to increase the air flow to these rooms. Once the system is installed, however, the only means of controlling the air flow is at the supply-air register.

Taking temperature readings of each room simultaneously, after the unit has been in operation long enough so that the readings are accurate, will help in adjusting the rate of flow through each register. This is a process of trial and error, and only small adjustments should be made over an extended period. When making ad-

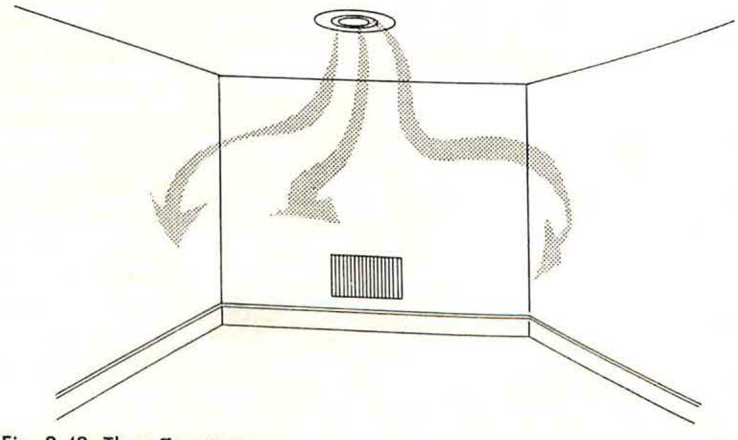
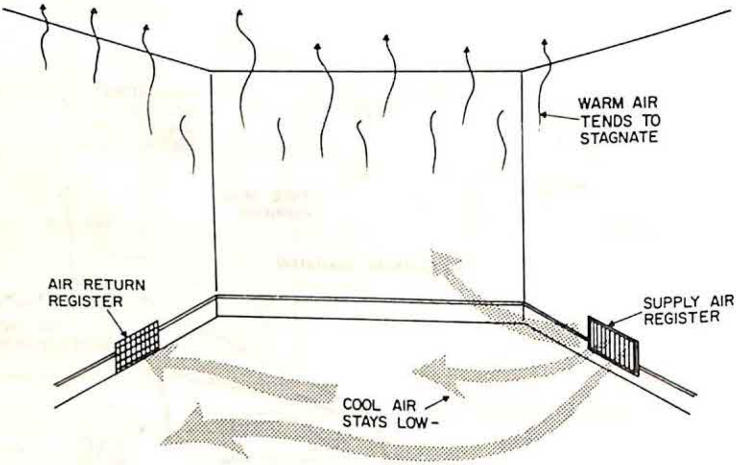


Fig. 2-42. The effect in a room where cooled-air registers are in the ceiling.

justments, be sure to take into account all factors not given by the temperature readings, such as changing conditions of night and day, the kind of living done in each room (playrooms, kitchens, bedrooms, offices, and workshops all have different temperature requirements), and conditions imposed by humidity, occasional overcrowding, etc.

Obviously, a single chapter in a book of this nature cannot cover all the many factors that go into an intelligently planned, skillfully installed system. If you are planning a central installation, specific instructions on capacities, balance checks, specifications, and other detailed data may be obtained from the manufacturer's literature supplied with the unit.



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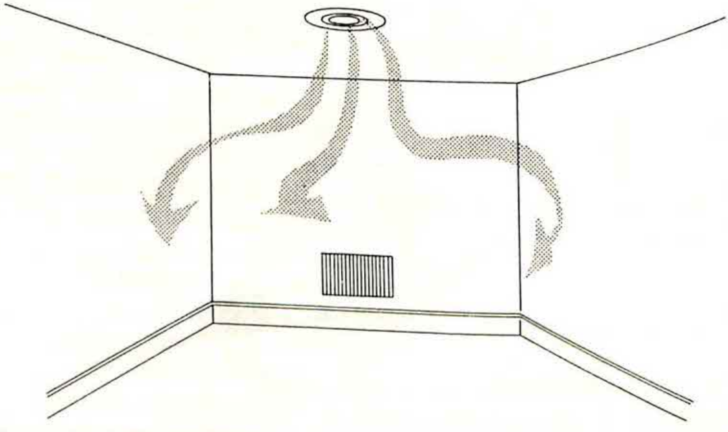

Fig. 2-42. The effect in a room where cooled-air registers are in the ceiling.

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CHAPTER THREE

The Electrical System

Having discussed the theory of air conditioning, it is necessary now to understand a little about how the motive power, electricity, is able to put the mechanical components of the air conditioner to work.

ELECTRICAL TERMS

Before discussing each electrical component, it is desirable to define some of the terms used in electrical work.

Voltage—Measure of electromotive force, or pressure. One volt equals the amount of electrical force which, when applied to a conductor having a resistance of one ohm, will produce a current of one ampere.

Amperage—The rate at which electrical *current* flows through a conductor as opposed to its pressure.

Ohms—The amount of resistance a conductor offers to an electric current.

Wattage—The unit of work performed by an electric force. It is related to horsepower measurement of mechanical force.

Phase—Electricity is delivered to users as single- or three-phase service. Homes, offices, stores, and small industrial plants use single-phase service (Fig. 3-1), which requires special motors capable of starting by themselves. In larger industrial plants, the more expensive three-phase service is used (Fig. 3-2), permitting simpler motor design and smoother operation.

Hertz (Cycles per second)—A measure of the *frequency* at which alternating current changes its direction. Most communities in the United States deliver 60-hertz current to users; however, some are 50-hertz.

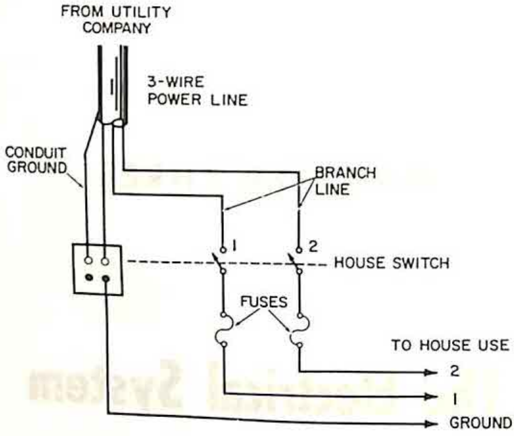


Fig. 3-1. Single-phase electrical service.

Alternating current (ac)—The most common electrical current. In a 60-hertz alternating current the generator changes polarity from plus to minus 120 times per second, resulting in surges of electricity from generator to user and back to the generator again 60 times per second. Alternating current is in widespread use in the United States simply because it is cheaper to generate and deliver than direct current.

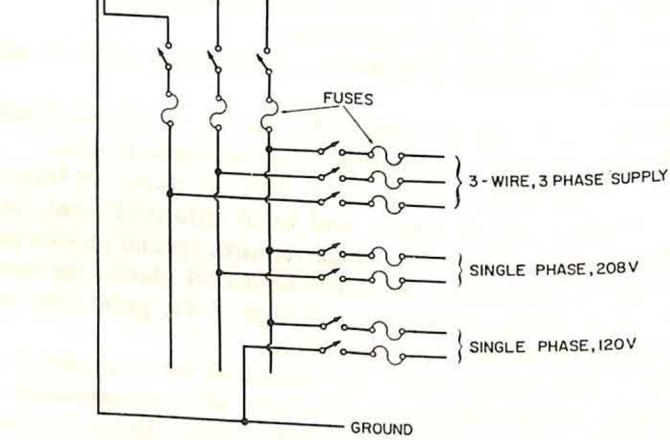


Fig. 3-2. Three-phase electrical service.

Direct current (dc)—Direct current always moves in the same direction—on one wire to the user, and back to the source on another wire. It is rarely used in homes in the United States as a primary source. When required for small variable-speed motors, dc is obtained from ac supplies by the use of a transformer and a rectifier.

FUSES

Because of the variations in load both at the utility company source and at the house distribution box, proper fusing of an appliance branch line is important. All manufacturers rate their appliances as to amperage under full-load conditions. Similarly, house wiring is rated for maximum amperage. If a single branch line in the home is rated at 15 amperes, the fuse rating in the line should never exceed this amount.

It follows, then, that the full-load capacities of any appliances operating in the line at the same time should not exceed 15 amperes. In many borderline cases, it is wiser to run a new branch line to the distribution box for exclusive use of the continually operating air conditioner.

Fuses are of two general types (Fig. 3-3). The familiar plug, or screw-in, fuse has its amperage rating marked on its face. In some screw-in fuses a thermal delay overlooks the initial surge of power required to overcome the inertia of a mechanical system. Such a fuse is particularly useful in air-conditioner applications, where the starting torque is usually three or four times the normal running power.

The cartridge fuse is more foolproof than the screw-in type, because the dimensions of the fuse differ according to rating, thus making it impossible to insert the wrong-sized fuse.

Many modern homes are equipped with circuit breakers, wherein an electromagnet breaks the circuit when its magnetic field is intensified to the maximum allowance. Circuit breakers are reset manually, rather than replaced like fuses. If the overload condition persists, the button will not stay reset, but will again break the circuit immediately.

(A) Screw-in.

(B) Cartridge.

Fig. 3-3. Two types of house fuses.

WIRING DIAGRAM

In the typical wiring diagram (Fig. 3-4) of a room air-conditioner, you can trace the circuit from the three-wire power cord through a single-phase system. The switch is mechanically designed so that the fan motor may be operated either alone or with the compressor, but the compressor may not be operated without the fan motor.

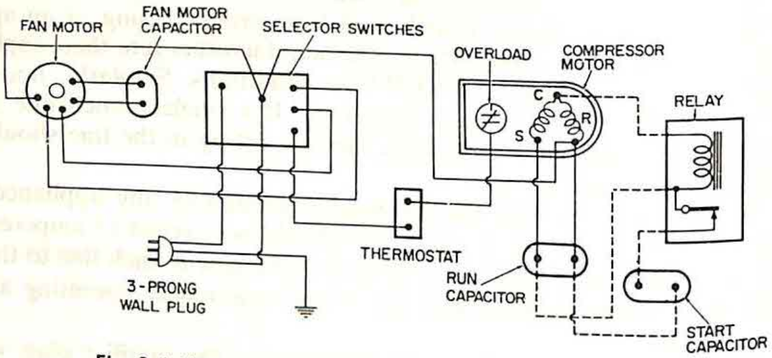


Fig. 3-4. Wiring diagram of a typical room air conditioner.

In a normal operating sequence, current is applied to the motor compressor through the overload protector, which opens the compressor circuit in event of excessive line voltage, or excessive current drain should the compressor become stuck. Initially the start capacitor (shown in dotted lines) is in the circuit until normal run speed is achieved, at which time it is disconnected by the relay (also in dotted lines). The run capacitor and both the start and run windings (S and R on the compressor terminals) remain in the circuit during compressor operation.

Upon reaching its preselected low setting, the thermostat disconnects the motor compressor from the circuit. The fan motor, however, is not governed by the thermostat, but continues to operate as long as the selector switch is in the ON position. There are normally two speed settings for controlling the fan: NORMAL FAN and HIGH.

To better understand the operation of the electrical system, let us now examine each electrical component in greater detail.

COMPRESSOR AND FAN MOTORS

Air conditioners, as we have said, use induction motors. Since the electric power service of most homes and small plants is of the single-phase type, self-starting motors are impossible without some

provision such as a start winding boosted by a start capacitor. The means of starting and maintaining the motor speed constitute the main differences between the types of motors used in air conditioners.

Split-Phase Motors

In a split-phase motor, phase difference is set up between two windings, both of which are located in the stator. The difference is accomplished by using many turns of thin wire in the start winding, to give it a high resistance. The main (run) winding is composed of fewer turns of heavier wire. It is the phase difference, or "split" phase, between the two windings that gives the induction motor its initial boost (Fig. 3-5).

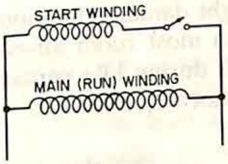


Fig. 3-5. Split-phase motor.

Once the rotor has begun to turn and the motor approaches its normal run speed, the start winding is cut out, usually by a relay.

Capacitor-Start, Induction-Run Motor

In a capacitor-start, induction-run motor the phase difference of two windings is still used at the start. However, the starting torque is increased by means of an electrolytic *start capacitor* (Fig. 3-6).

Capacitor-Start, Capacitor-Run Motor

An additional capacitor, called the *run capacitor*, is permitted to remain in the circuit even after this motor has started. The run capacitor increases the power of the motor (Fig. 3-7).

Permanent Split-Capacitor (PSC) Motor

The PSC is the latest in a series of innovations for air-conditioner motors (Fig. 3-8). The PSC motor has no start capacitors and re-

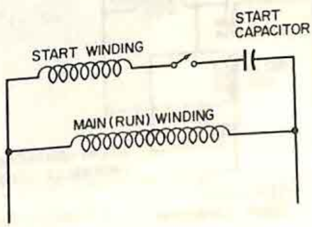


Fig. 3-6. Capacitor-start, induction-run motor.

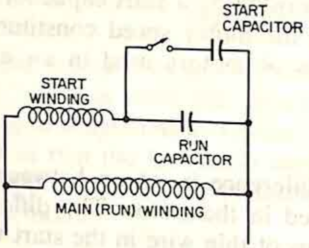


Fig. 3-7. Capacitor-start, capacitor-run motor.

lays. Because of its low starting torque, it must be used with air conditioners whose high- and low-side pressures become equalized while the compressor is not operating. If the head pressure in the compressor were too great at start time, the motor would not be able to overcome the additional load, and the overload which would result might damage the motor.

Since in most room air-conditioning systems the head pressure is relieved during idle periods, the low starting torque of the PSC motor is not objectionable.

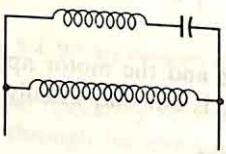


Fig. 3-8. Permanent split-capacitor motor.

Relay

The relay keeps the starting force in the circuit until the motor has attained its normal run speed (usually about three seconds). At that time, the relay breaks the circuit of either the start capacitor or start winding, depending on the type of starting force used. There are two types of relays—*voltage* or *current*-operated.

The voltage type (Fig. 3-9) is used on capacitor-start motors only. Its contacts are normally closed so that in the first few sec-

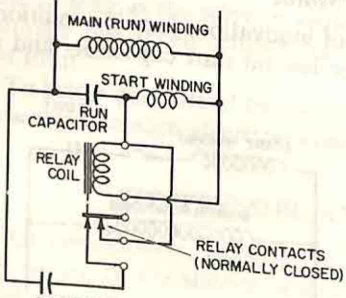


Fig. 3-9. Voltage-type relay circuit.

onds at the start, it and the start capacitor are in the circuit. As the motor picks up speed, a current induced in the relay energizes a coil. At about 85 percent of motor speed, the current is strong enough to overcome the normally-closed relay contacts, and the circuit to the start capacitor opens. Note that the start winding stays in the circuit, even after the relay is energized.

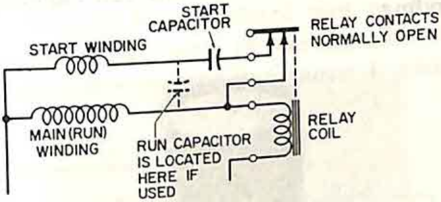


Fig. 3-10. Current-type relay circuit.

In the current type of relay (Fig. 3-10), the contacts are normally open. The instantaneous surge of current (amperage) at the very start actuates an armature, which closes the start-winding circuit, and the motor starts. When the motor reaches its normal run speed (again in about three seconds), the current drops to normal. The weight of the armature now overcomes the force of the coil, and the start winding (or start capacitor, if one is used) is disconnected from the circuit. Current relays may be used without start capacitors; hence, they are ideal for split-phase motors.

Start Capacitor

The start capacitor (Fig. 3-11) increases the initial power (torque) of the start winding in an induction motor. It is always

Courtesy Cornell-Dubilier Electronics

Fig. 3-11. The start capacitor.

used with a relay, and the two are usually matched so that one should not be replaced without also replacing the other.

Run Capacitor

The run capacitor (Fig. 3-12) increases the power of the motor during run speed. The start winding is not cut out when the motor attains run speed but, together with the run capacitor, constitutes an auxiliary winding.

Courtesy Cornell-Dubilier Electronics

Fig. 3-12. The run capacitor.

Motor Overload

The motor overload (Fig. 3-13) or overload protector guards the motor against fluctuations of load or line voltage. If the head pressure, for instance, suddenly becomes too high, the resulting surge of current might be so great that it would burn out the motor. Too low a house voltage could prevent the rotor in a motor from turning, and the resultant current drain might also burn out the motor. The overload protects the motor in both instances.

At the heart of the overload is a small curved disc made from two metals with different heat coefficients and bonded together. When a predetermined amount of heat is applied to the disc, it

(A) Closed.

(B) Open.

Fig. 3-13. Operation of the motor overload.

snaps into a curve opposite to its normal one. This opens the circuit for as long as the heat persists. When the temperature returns to normal, the overload snaps back into its original shape, again closing the circuit and permitting normal operation to resume.

THERMOSTAT

While it can certainly be considered part of the electrical circuit, the thermostat is also part of the mechanical refrigeration system. Its operation was covered in Chapter 1, under "Controls."

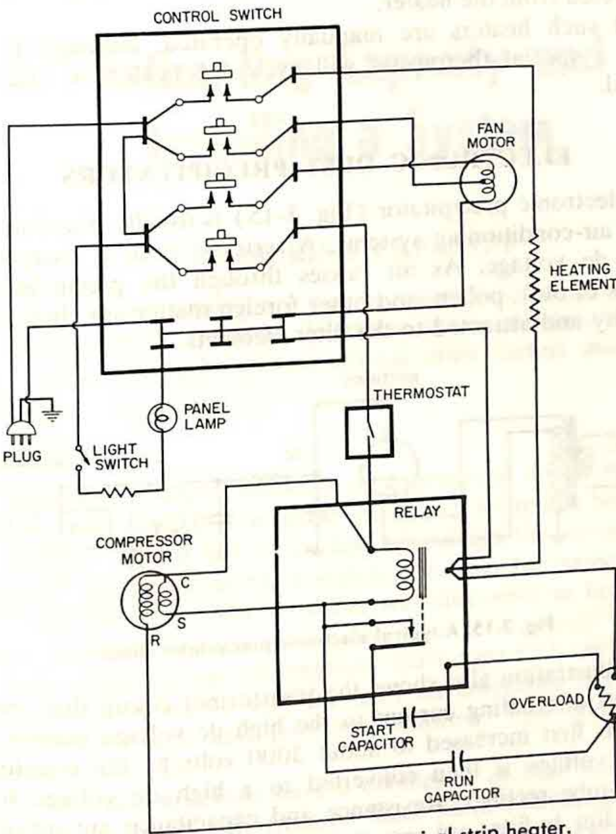


Fig. 3-14. Wiring diagram of a typical strip heater.

HEATING ELEMENTS

Some air conditioners use strip heaters as a source of auxiliary heat on chilly days. The heat from the element is distributed in

the room by the blower system of the unit. A typical wiring diagram is shown in Fig. 3-14.

There is no relation to the number of Btu's supplied to the room by the heater, and the Btu's taken from the room in cooling. The heating element is entirely separate from the cooling system (unlike the reverse-cycle operation of an air conditioner equipped with a heating cycle).

The wattage of a heater is obtained in the same manner as any heating element: The voltage supplied to the unit is multiplied by the rated current in amperes. Having obtained the wattage, multiplying by the factor 3.4 will give roughly the Btu/hr which can be expected from the heater.

Most such heaters are manually operated, although in some models a special thermostat will cycle the heater on and off as required.

ELECTRONIC DUST PRECIPITATORS

An electronic precipitator (Fig. 3-15) is usually found in larger central air-conditioning systems. A series of grids is charged with a high dc voltage. As air passes through the precipitator, the particles of dust, pollen, and other foreign matter are charged with electricity and attracted to the filter elements.

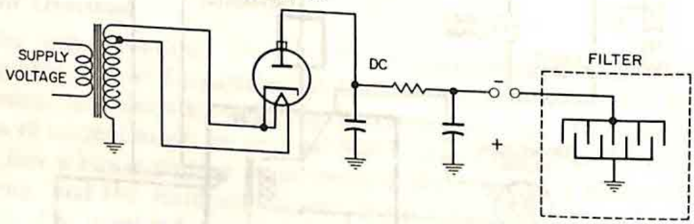


Fig. 3-15. A typical electronic precipitator circuit.

The illustration also shows the transformer circuit that converts 115 volts alternating current to the high dc voltage needed. Line voltage is first increased to about 3000 volts by the transformer. The ac voltage is then converted to a high dc voltage by the vacuum-tube rectifier. Resistance and capacitance are introduced into the line to filter out any variations in the output voltage.

Other electrical components that are peculiar to special installations, such as the dual pressure cutout control, are described in connection with their special applications.

CHAPTER FOUR

Estimating Capacity and Installing a System

MEASURING CAPACITY

Before an air conditioner can be selected for a given location, a survey must be made to determine the requirements. In addition to the area to be cooled, several other factors must be considered.

Building Factors

Buildings, whether dwellings or commercial structures, are designed primarily (in temperate climates) to retain heat as long as possible. This is one of the few advantages the air-conditioning engineer has in designing a system, because the same principles that keep the heat inside in winter will also serve to keep the heat out in summer.

Some disadvantages the engineer must cope with are inadequate wiring, large windows with the least advantageous exposure, and odd-shaped rooms and interior furnishings that complicate the natural flow of air.

All building materials have a coefficient of heat transfer—that is, some materials will transmit heat more readily than others. These values have been worked out so that it is possible to figure in advance the amount of *cooling capacity* required to cool a room of a certain set of characteristics.

The National Electrical Manufacturers Association (NEMA) developed the simple form reproduced in Fig. 4-1, for estimating the cooling-load requirements of a room. Other such forms are

COOLING LOAD ESTIMATE FORM FOR ROOM AIR CONDITIONERS

Customer *Mrs. Sgoutt* Address *304 Chapel*

Estimated by *JKH* Date *6/12* Space to be used for *liv rm.*

Heat Gain From	Quantity	Factors: Night	Factors: Day				Btu/Hr (Quantity x Factor)
1. WINDOWS heat gain from direct radiation of the sun (total all windows for each exposure, but use only the largest load).			No Shades*	Inside Shades*	Outside Awnings*	(Area x Factor)	
Northeast	___ sq ft	0	60	25	20	___	
East	*18* sq ft	0	80	40	25	___	
Southeast	___ sq ft	0	75	30	20	___	
South	*18* sq ft	0	75	35	20	___	
Southwest	___ sq ft	0	110	45	30	___	
West	___ sq ft	0	150	65	45	___	
Northwest	___ sq ft	0	120	50	35	___	
North	___ sq ft	0	0	0	0	___ Use only the largest load	*450*
			*These factors are for single glass only. For glass block, multiply the above factors by 0.5; for double-glass or storm windows, multiply the above factors by 0.8.				
2. WINDOWS, heat gain by conduction (Total of all windows)							
Single glass	*36* sq ft	14	14				*504*
Double glass or Glass block	___ sq ft	7	7				___
3. WALLS (based on linear feet of wall)							
a. Outside walls			Light Construction	Heavy Construction			
North exposure	___ ft	30	30	20			___
Other than North exposure	*24* ft	30	60	30			*720*
b. Inside walls (between conditioned and unconditioned spaces only)	*24* ft	30	30				*720*

Fig. 4-1. Form for estimating cooling-load requirements

COOLING LOAD ESTIMATE FORM (Continued)

Heat Gain From	Quantity	Factors Night	Factors Day	Btu/Hr (Quantity x Factor)
4. ROOF OR CEILING (Use one only.)				
a. Roof, uninsulated	____ sq ft	5	19	
b. Roof, with 1 inch or more insulation	____ sq ft	3	8	
c. Ceiling, with occupied space above	144 sq ft	3	3	
d. Ceiling, insulated, with attic space above	____ sq ft	4	5	432
e. Ceiling, uninsulated, with attic space above	____ sq ft	7	12	
5. FLOOR (disregard if floor is directly on ground or over basement)	144 sq ft	3	3	432
6. NUMBER OF PEOPLE	2	600	600	1200
7. LIGHTS & ELECTRICAL EQUIPMENT IN USE	300 watts	3	3	900
8. DOORS & ARCHES CONTINUOUSLY OPEN TO UNCONDITIONED SPACE (linear feet of width)	0 ft	200	300	0
9. SUB-TOTAL	xxxxxx	xxx	xxx	5358

10. TOTAL COOLING LOAD (Btu per hour to be used for selection of room air conditioner(s) 5358 (Item 9) x 1 (factor from map) = 5358

Courtesy National Electrical Manufacturers Association

of a room (for use with room air conditioners only).

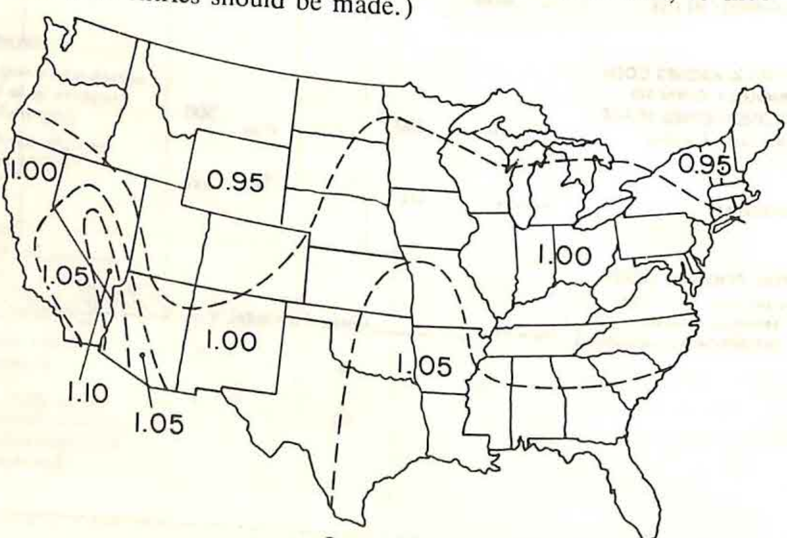
available to the air-conditioner installer. Only the factors are different; the principles are all the same in every form of this type.

The end result of the form is expressed in Btu per hour, the method most manufacturers of packaged air conditioners use to express capacity. Should the capacity of the air conditioner be expressed in *tons of refrigeration*, it will be necessary to divide the estimated figure by 12,000 to convert Btu per hour into tons.

It should be emphasized that the cooling-load estimate form applies only to completely self-contained units such as room air conditioners. It cannot be used to figure multiroom installations or the capacity of a central system. Also, extreme humidity will not be met by the suggested capacity, but should be figured separately and used as a correction factor.

The cooling-load estimate form is based on an environment with a dry- and wet-bulb temperature of 95 degrees and 75 degrees F, respectively. It can be used anywhere in the continental United States by applying the correction factors shown on the map in Fig. 4-2. "Day" factors are given for kitchens, offices, and other rooms to be occupied primarily during daylight hours, and "night" factors are given for bedrooms. Where a factor of 1.0 is indicated on the map, the effect of the climatic region can be ignored.

The following instructions are numbered to correspond to the steps of the cooling-load estimate form. (The figures written in longhand on the form are for a hypothetical installation, to illustrate how entries should be made.)



Courtesy National Electrical Manufacturers Association

Fig. 4-2. Multiplying factors for use with the cooling-load estimate form for each climatic region of continental United States.

1. Calculate the area in square feet of each window opening. Total all the window area for each exposure. Multiply the total in "quantity" column by the applicable factor for each exposure, but use only the largest figure thus arrived at. Note that glass block, double glass, or storm windows require an additional multiplication factor.

   Now take the largest figure you have entered in the "Factors" column and enter it in the column headed "Btu/Hr."
2. Using the applicable factor, multiply the sum of the area in square feet of every window in the room, regardless of exposure. Enter both figures (if both single- and double-glass windows are found in the room) in the "Btu/Hr" column.
3. Add up the linear feet of (a) all outside walls facing north, (b) all other outside walls, and (c) all inside walls connected to an *unconditioned* area. Do not include any walls connected to conditioned areas.

   All doors should be considered part of the walls. Walls which are permanently shaded by other buildings, or by other obstructions, either natural or man-made, should be considered as having a northern exposure. Light construction is any noninsulated frame or masonry wall eight inches or less in thickness. Any insulated frame wall, or any masonry wall more than eight inches thick, is considered heavy construction.

   Multiply the sum of the linear feet of each of the three types of walls by the appropriate factor, and enter the result in the "Btu/Hr" column.
4. Selecting the appropriate category, multiply the total square feet of the ceiling space by the applicable factor. Enter the result in the "Btu/Hr" column.
5. Multiply the total square feet of floor area by the factor. If the floor is over a basement, or rests directly on the ground, disregard this entry entirely.
6. The number of people who normally use the room is multiplied by the factor. If only one person is normally present, use a minimum of two.
7. Add the wattage of all lights and other electrical equipment, except the air conditioner itself, that will be in normal use when the equipment is operating.

   Multiply the sum by the given factor and enter in the "Btu/Hr" column.
8. If any doors or arches are continuously open to an unconditioned space, multiply their linear width by the factor and enter in the "Btu/Hr" column.

If any arch or double doors exceed five feet, the adjoining space into which they open must be considered part of the room and included in all measurements.

9. Total all entries in the "Btu/Hr" column.
10. After locating your area on the map (Fig. 4-2), multiply by the appropriate geographical factor.

This figure, in Btu per hour, represents the desired capacity of the unit to be installed in the room.

Horsepower as Capacity

Horsepower is the rating of the air-conditioner *power source* (the electric motor driving the compressor). At best it can give only a rough indication of the capacity of the entire system. The rest depends on such factors as the compressor displacement, rate of flow of the refrigerant, cubic feet per minute (cmf) of the air flow, capacities of the evaporator and condenser.

Unlike the relationship between *tons of refrigeration* and Btu per hour, no clear-cut relationship exists between horsepower and cooling capacity. It is erroneous to speak of one horsepower as being equivalent to one ton of refrigeration, except for certain water-cooled central systems. How close a packaged air conditioner comes to the 1 horsepower/1 ton ratio depends on how efficient the system is. For this reason, you should make every effort to determine the cooling capacity of the unit in Btu per hour or tons of refrigeration before deciding on an installation.

Voltage and Amperage

Since the larger-horsepower electric motors require more current to perform their work efficiently, units having motors of greater than ¾ horsepower must be wired to a 230-volt circuit. This requires wiring a new branch circuit from the power source if there are no 230-volt lines in the building. Since most homes, especially more recent ones, are equipped with a single-phase, three-wire power supply, wiring a branch circuit is no problem.

One small problem that sometimes comes up, however, is fluctuations of voltage in the power supply. In some areas of the United States, the primary source of supply delivers 208 volts. In other areas, it may exceed 230 volts, causing as much as a 50-percent increase over a component's rated wattage.

In these isolated instances, some manufacturers make available a transformer which steps the air-conditioner supply voltage down from 230 volts to 208 volts, or vice versa. The transformer also maintains a more even voltage to the air conditioner, should the power decline during peak-load periods. The manufacturers' instructions for installing the transformer should be followed.

In many older homes that were wired before appliances became so prevalent, amperage is a problem. Some local electrical codes prohibit the installation of a major appliance in a branch circuit shared by other motor-driven electrical appliances. Here an air conditioner drawing low amperage, yet maintaining a relatively high Btu-per-hour capacity, is a must. The popular 7.5-ampere, ¾-horsepower packaged unit, providing a range of 6,000 to 7,000 Btu per hour, answers this need. Most manufacturers of room air conditioners include such a model in their lines.

Two things must be uppermost in the mind of the technician when installing a room air conditioner. The first is the safety of the installation, from both a physical and electrical standpoint. The second is the efficiency of the unit, which will be greatly affected by proper or improper installation.

Air conditioners, even the smaller room types, are quite heavy. Since most installations are of a semipermanent nature, it is important that supporting window framing be in good condition, to receive the brackets and other hardware supplied for installing the unit.

Electrical wiring, particularly for 230-volt supplies, should be carefully checked for worn-out insulation or loose connections. Normally the unit is grounded by a three-wire electrical plug, the third wire being the ground. Do not defeat the purpose of the ground by snipping off the third pin and using an ordinary two-hole receptacle. By the same token, when using the three-hole receptacle for which the plug was designed, be sure the receptacle is properly grounded to the nearest water pipe.

A good installation will *not* improve the efficiency of the unit, but it will permit the unit to work at its rated capacity. On the other hand, a poor installation may seriously impair the cooling efficiency, and may even lay the groundwork for premature failure.

The most common installations for room air conditioners are *window*, *transom*, and *through-the-wall*. A window installation, the most common of the three, is the easiest and usually the most convenient. Transom installations (above doors, etc.) are sometimes necessary in stores and offices having only large plate-glass windows. A through-the-wall installation is not usually warranted because of the expense involved in heavy construction, repainting, and repairing. However, where there are no windows in the wall that is the only logical location for the unit, a through-the-wall installation may be the only alternative.

Manufacturers of room air conditioners supply installation kits, which are designed to meet almost any requirement. It is necessary to know the kind of installation (double-hung window, casement window, etc.), when ordering the air conditioner, so that the

proper kit may be supplied with the unit. Instructions for installation are provided with the kits.

WINDOW INSTALLATIONS

The two types of windows of concern here are first the ordinary double-hung window (Fig. 4-3), in which the window sashes

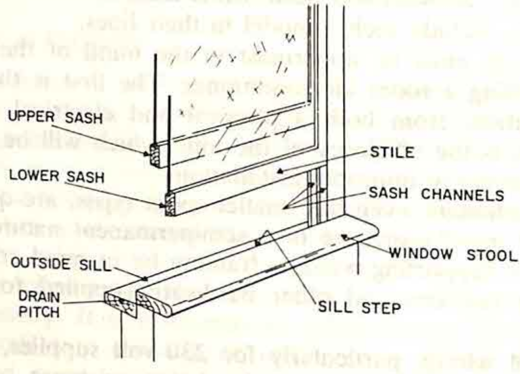


Fig. 4-3. Double-hung window construction.

travel up and down in channels adjacent to each other, and the casement window (Fig. 4-4), usually made of metal framing with hinged sashes that open outward. Note the nomenclature of the various parts of the window; it will help in following the steps of the installation procedures.

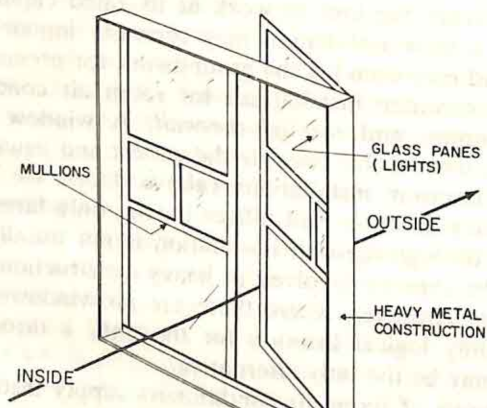


Fig. 4-4. Casement window construction.

Double-Hung Window

In a double-hung window installation, the air conditioner is anchored firmly on the sill, and it is prevented from tipping over by side frames which slide out from the unit cabinet and engage side angle brackets fitted into the sash channels as shown in Fig. 4-5. Further support is obtained by attaching the top bracket to the sash stile. In some installations, it is necessary to attach the air conditioner to the stool as well as to the outside sill by means of channels. Because the height and pitch of sill steps may vary, manufacturers provide a means for adjusting the pitch of the cabinet (about one-fourth inch per foot) so that it tilts to the outside, allowing condensate to fall directly to the ground rather than run down the walls.

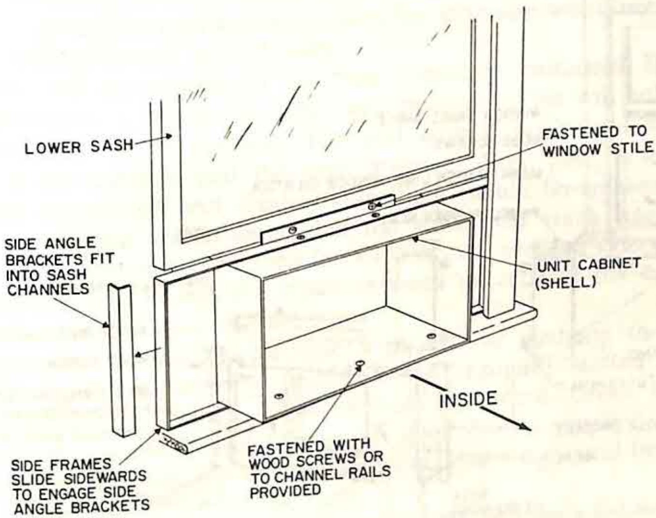


Fig. 4-5. Simplified diagram of a typical double-hung window installation.

The height and width of the clear space with the sash open must, of course, be great enough to admit the air-conditioner cabinet. Normally the height of the air conditioner will be no problem, since most double-hung windows are high enough.

To fill the space created by varying width of windows, all installation kits are provided with side filler panels, usually accordion-folded plastic, to fit any space (up to 40 inches) not taken up by the width of the cabinet. For wider windows, special installation kits are provided. To adapt the filler panel to the space to be filled, only one vertical cut is necessary. Some side panels have grooves spaced

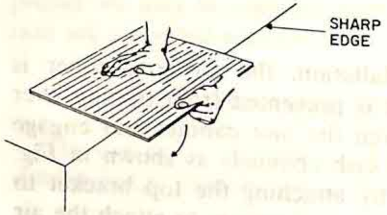


Fig. 4-6. Breaking a side panel along the grooved lines.

about one-half inch apart; the panel can be broken cleanly at the desired groove by merely placing it over a sharp edge as shown in Fig. 4-6.

Now look at the typical installation diagram in Fig. 4-7. It is desirable to get the room air conditioner as high off the floor as

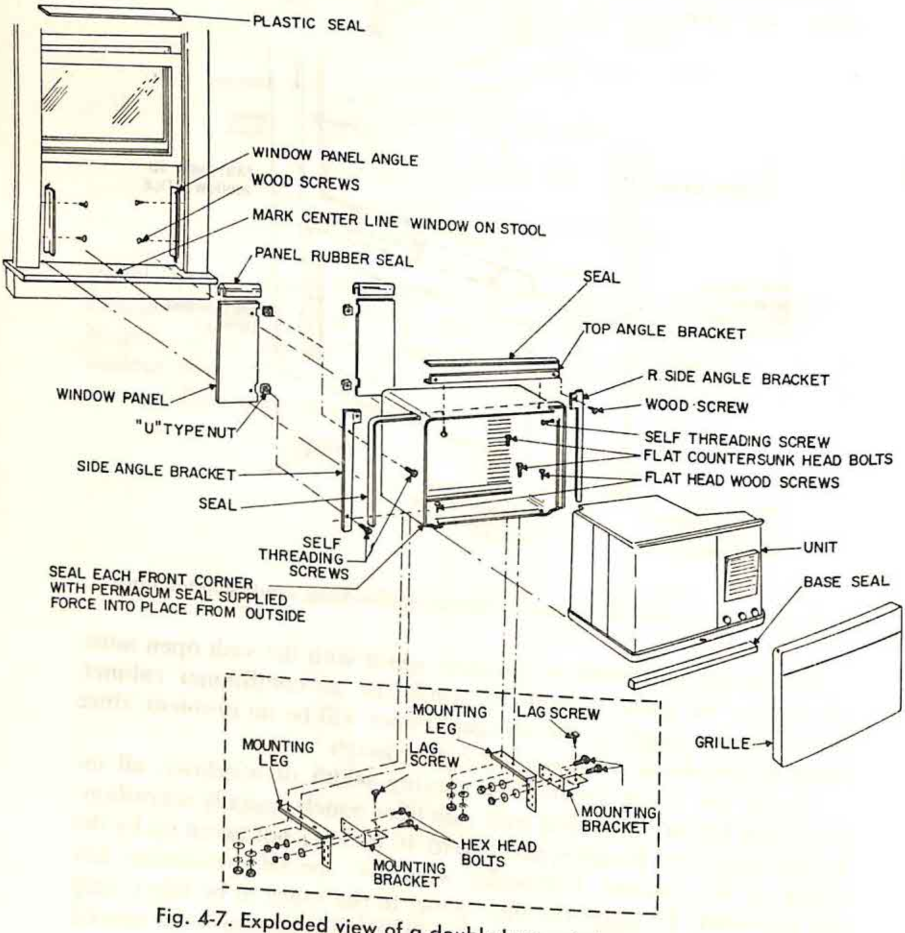


Fig. 4-7. Exploded view of a double-hung window installation.

possible, because cold air sinks. However, because the unit requires a firm base, it is normally installed in the lower sash opening of a double-hung window, where it can rest on the sill.

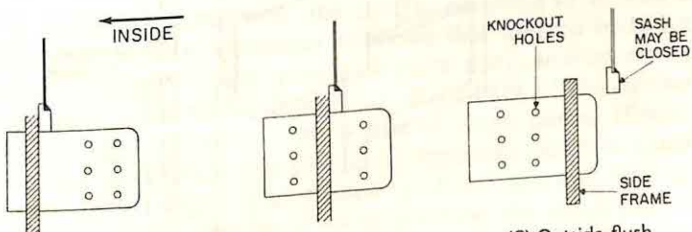
For a neat installation, the unit should be centered in the window, with side panels of equal width. First mark off the center of the sill; this mark will serve as the basis for all measurements. The instructions contained in the kit will usually give measurements, with allowances already figured in for unit width, height, and other known dimensions.

In the installation given, the side angle brackets are first screwed into the recesses of the sash channels on each side of the window frame. Now the cabinet is slid off the unit. The center line of the cabinet is lined up with the center line marked off on the sill, and the cabinet is positioned for (1) inside flush mounting, (2) outside flush mounting, or (3) middle mounting (see Fig. 4-8). Most cabinets are provided with knockout holes for alternate mountings, and button plugs to seal unused holes.

After the air conditioner has been correctly positioned, frames are extended to engage the side angle brackets. This will hold the cabinet securely in position. The seal strip is positioned on the top of the cabinet, and the sash lowered. Now pilot holes are drilled into the sill and window stile; they should be smaller than the screws, but not so small that the wood will crack when the screws are installed. The sash is raised again, and the side panels inserted, cut to fit into the space between the side of the cabinet and the window channel.

Some installation kits provide a means for wedging the side panels tightly. A wedging member with diagonally slotted screw holes is supplied which, when pushed downward, closes tightly against the panels. Plastic foam seals may also be supplied; these fit over the top edge of the side panels, making a tight seal between the panels and bottom of the sash.

Now the cabinet is screwed down securely into the window stool (or into front and rear channels if provided), the sash is lowered,



(A) Inside flush. (B) Middle mounted. (C) Outside flush.

Fig. 4-8. The three types of window mountings.

and the top bracket is screwed to the window stile. Usually it is desirable to also lock the upper sash in the closed position by fitting blocks of wood into the sash channels.

Any small gaps at joints and corners should be plugged with plastic foam or other insulation. This material, usually supplied with the kit, should be packed into the gaps from the outside.

Now it is only necessary to slide the unit into the cabinet (usually on the tracks provided on the cabinet floor) and secure it with the bolts and nuts provided. Some air conditioners have "externally mounted" compressors; that is, their spring mounts are on the outside of the housing. These compressors are usually tied down for shipping by brackets or clamps, which must be removed before the compressor is run. Externally mounted compressors also have provision for leveling, which should also be attended to before running the unit. The final step, after replacing the front panel, is to plug in the unit.

A separate unit and cabinet shell installation such as the one just described is rare, even among the larger Btu capacity units. Most manufacturer's models are now supplied as one piece, with an adjustable, self-leveling center bracket on which the unit rests on the window sill.

Some local building codes limit the distance a unit may extend beyond the building line, so be sure to check local ordinances before planning an installation. In any event, if the unit extends more than a foot beyond the outer sill, it would be wise to use wall brackets (available with most installation kits) for further support.

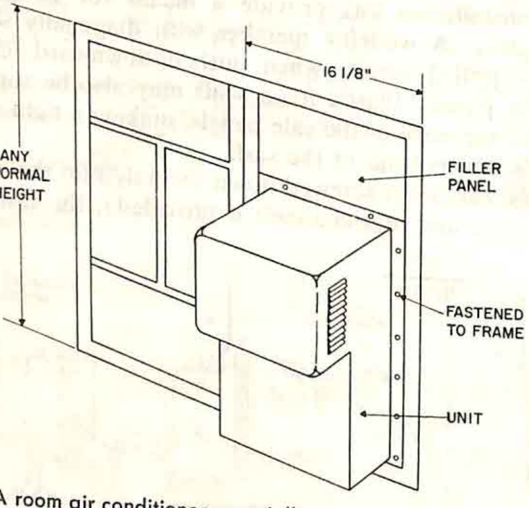


Fig. 4-9. A room air conditioner especially constructed to fit a standard casement window.

Casement Window

Casement window installations pose special problems for the installer. Fig. 4-9 shows a specially constructed room air conditioner which fits *standard* casement window openings of 16⅛-inch width and any height greater than about 30 inches. The entire casement window and all its hardware are removed and the air conditioner placed in the frame opening. (A filler panel covers any excess space above the unit.) It is only necessary to secure the unit to the metal framing, being sure to weatherstrip all junctures. Proper pitch for these units is automatic—that is, if the unit is properly mounted, the condensate will drip toward the outside. The unit just described is mounted wholly outside the room, with its front facing into the room. Because the unit is mounted to a metal frame, it needs no elaborate bracing, even though it may extend beyond the building line. However, it is wise to check local building codes before planning this installation.

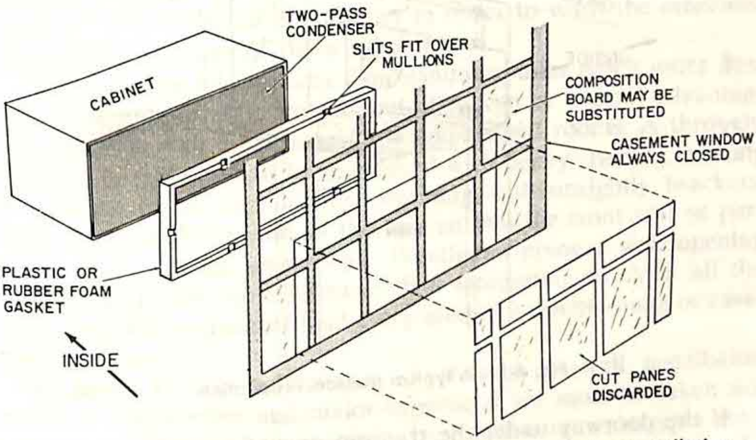


Fig. 4-10. Cutting the glass panes for a wide casement-window installation.

In the foregoing installation, the unit is designed to fit into a standard space exactly. Casement windows that are too wide for this type of installation entail quite a bit more work. It is necessary to cut the glass panes to the dimensions of the back of the cabinet (Fig. 4-10). This may mean cutting part of single panes. (Sometimes a neater installation may be had by replacing the glass panes with composition board.) The window mullions are *not* cut—all that is required is free passage of air to and from the condenser.

The air conditioner is then mounted flush with the casement window (while closed). A foam-rubber gasket seals the juncture

between the edges of the cut glass panes (or composition board) and the back of the cabinet. A two-pass condenser air conditioner is necessary for this installation. This type of unit is open only in the back; it has no side louvers.

TRANSOM INSTALLATIONS

A transom installation (Fig. 4-11) requires experience, patience, and a good deal of thought. Two special considerations are the construction involved and the fact that people pass beneath the air conditioner. As mentioned previously, sometimes the only place to install a room air conditioner is in a transom, because of the large show windows in some stores and offices, and because a through-the-wall installation would be uneconomical.

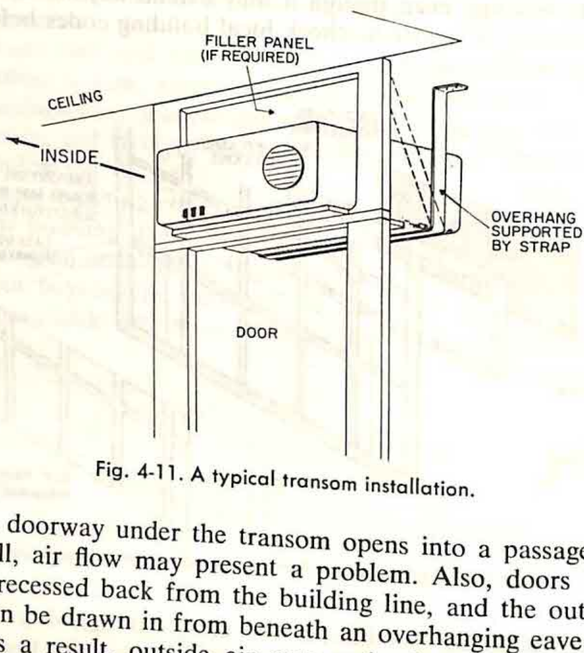


Fig. 4-11. A typical transom installation.

If the doorway under the transom opens into a passageway or short hall, air flow may present a problem. Also, doors are frequently recessed back from the building line, and the outside air must then be drawn in from beneath an overhanging eave or balcony. As a result, outside air may recirculate through the condenser, greatly impairing its function.

Another problem, where the air conditioner is located next to a short hall, is recirculation of *cooled* air, causing a freeze inside the unit. Both conditions may be partially corrected by installing suitable ductwork leading to open areas, although it is far better to avoid the situation entirely by using an alternate location.

A transom installation also means that the unit is installed above a door through which people must pass. In a window installation,

condensate is permitted to drop outside (unless the unit is equipped to scoop up the condensate and blow it across the condenser), where it falls on grass or another part of the building, etc. In a transom installation, of course, the condensate must be led off through a pipe to a drain.

Since normal brackets may interfere with the opening and closing of the door beneath, the overhang of the unit is supported by steel straps, usually from the ceiling. A transom installation, unlike a window job, requires two men.

THROUGH-THE-WALL INSTALLATION

As was touched on previously, the most expensive installation is through a wall, although in many respects it is the most satisfactory. Since many homes were not built with air conditioning in mind, both the location and construction of windows may create special problems for the installer. Also, there is always the ever-present problem of window draperies and blinds, as well as the need to remove the air conditioner in order to wash the otherwise inaccessible surfaces of the window panes.

Walls, having greater area than windows, offer much more flexible choices of location for the unit. This can be a great advantage when planning air conditioning for odd-shaped rooms. A through-the-wall installation can be reinforced with heavy framing, making it unnecessary to support the overhang with unsightly brackets. Also, it is possible to mount the unit so that the front will be perfectly flush with the inside wall. Weatherstripping a wall opening is likely to be far more effective than attempting to caulk all the many possible avenues of heat entry around a double-hung or casement window.

So much for the advantages. A through-the-wall installation means a major effort and major expense. Care must be taken not to cut into places where conduit, heat ducts, or waterpipes may pass through. If at all possible, consult the building plans. Usually a building permit must be obtained, since a major modification must be made.

The opening, whether through masonry, framing, or other construction, must be made large enough to permit fitting the rough framing and molding around the cabinet as shown in Fig. 4-12. By means of brackets supplied with the unit, the cabinet is fastened to the framing and carefully weatherstripped. Be doubly sure the unit has the proper pitch, and all louvers and air-return openings are unobstructed. Finish framing may be supplied with the unit, or millwork may have to be installed on both the inside and outside walls for an attractive installation.

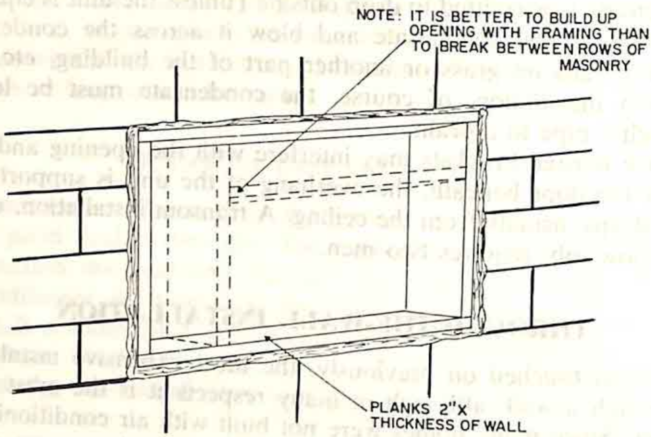


Fig. 4-12. Framing an opening through masonry for a through-the-wall installation.

INSTALLATION CHECK LIST

1. Make sure that the *unit* has the correct pitch for proper drainage. This pitch (one-fourth inch per foot) may be achieved automatically when the cabinet is perfectly level, or the cabinet may have to be pitched (consult the instructions in individual installation kits).
2. If storm windows are installed in the window, the sill may have to be built up so the cabinet will clear the bottom rail of the storm-window frame.
3. If return air is admitted to the unit through openings in the bottom front of the cabinet, make sure the window stool does not obstruct them. If necessary, build up the stool with lumber, allowing at least one inch between it and the cabinet.
4. If an outside flush mounting is planned, some means of carrying off the condensate should be provided, to prevent unsightly streaking of outside walls. Drip pans are available in most installation kits.
5. If the installation results in an enclosed space where rain water may collect, drill drainage holes in the outside sill.
6. Since the outside air must be considerably cooler than the condenser temperature, the air conditioner must be located in a wall with the least exposure to the direct rays of the afternoon sun.
7. Check the manufacturer's instructions carefully, to make sure they have been fully carried out. Be especially careful to remove all shipping brackets.

CHAPTER FIVE

Tools and Test Equipment

An expert serviceman requires a complete set of tools and test equipment to do an expert job of testing, servicing, and repairing air conditioners. How elaborate this equipment will be depends on your inclination. The list in this chapter includes those items necessary to do a thorough job in as short a time as possible.

Most equipment described is commercially available through refrigeration and air-conditioning wholesalers. Some servicemen, by investing their own time, ingenuity, and a little money, design and build their own systems for pumping out a unit, for charging, and even for cutting open a defective compressor. The components for such systems, as well as the systems themselves, are available in capacities that will permit processing one or fifty units a day.

ELECTRICAL TEST EQUIPMENT

To understand the functions of each of the next four instruments, it might be well to compare an electrical current with water flowing through a pipe. The *ohmmeter* measures the amount of resistance encountered by the current (water) as it travels through the wire (pipe). The larger the wire size (pipe diameter), the less the resistance offered to the current; hence, the greater the current. An *ammeter* measures the rate of a current (cubic feet per minute of water) past a given point in the circuit. A *voltmeter* measures electromotive force (pressure of water in the pipe without regard to flow). A *wattmeter* measures the amount of work a current performs (horsepower of water flow). One watt equals 1/746th horsepower.

Ohmmeter

Ohmmeters used in air conditioning serve chiefly to test electrical continuity for shorts in circuits, segments of circuits, switches, thermostats, and start and run capacitors, and other electrical components. An ohmmeter measures resistance in a circuit. If it is applied between points where continuity is supposed to exist and the needle fails to move, the circuit is open and the component being checked should be replaced. If the needle moves, the circuit is closed and can be considered functional (this does not apply to capacitors—see the following chapter for the use of an ohmmeter to check them).

Ammeter

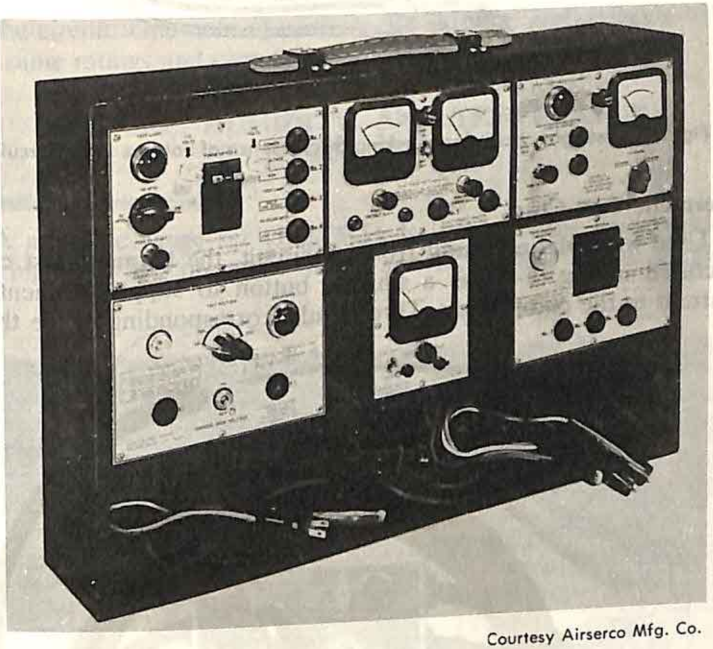
Air-conditioning servicemen will find greater convenience in using a hook-on ammeter (Fig. 5-1) because it does not require disturbing the circuit for a reading. Ammeters are used for measuring current, and the reading is then compared with the published specifications and ratings of the unit found in the manufacturer's service literature.

Courtesy Weston Instruments Div., Daystrom, Inc.

Fig. 5-1. A hook-on ammeter.

Voltmeter

The voltmeter is a necessary tool for determining high- or low-voltage conditions that may contribute to unsatisfactory cooling. Models are available for checking both dc and ac voltages. Circuit components, as well as the house supply voltage, can be checked with a voltmeter.



Courtesy Airserco Mfg. Co.

Fig. 5-2. Hermetic analyzer and electrical tester.

Wattmeter

A wattmeter helps the serviceman determine how efficiently the motor compressor and other components are functioning. Low readings where high readings are normal indicate weak or worn-out components in the circuit, such as capacitors.

All four of the foregoing instruments may be combined into one convenient piece of test equipment called a hermetic analyzer and electrical tester (Fig. 5-2).

Continuity Test Light

The test light shown in Fig. 5-3 is used to test for the presence of voltage in the circuit. No glow means no voltage, of course.

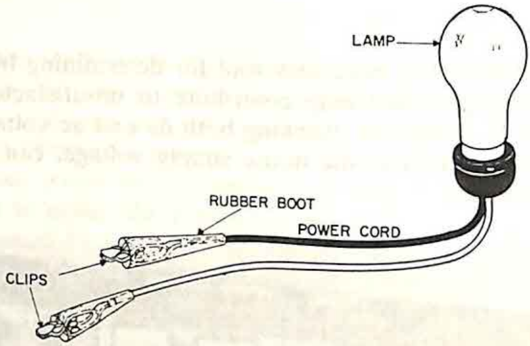
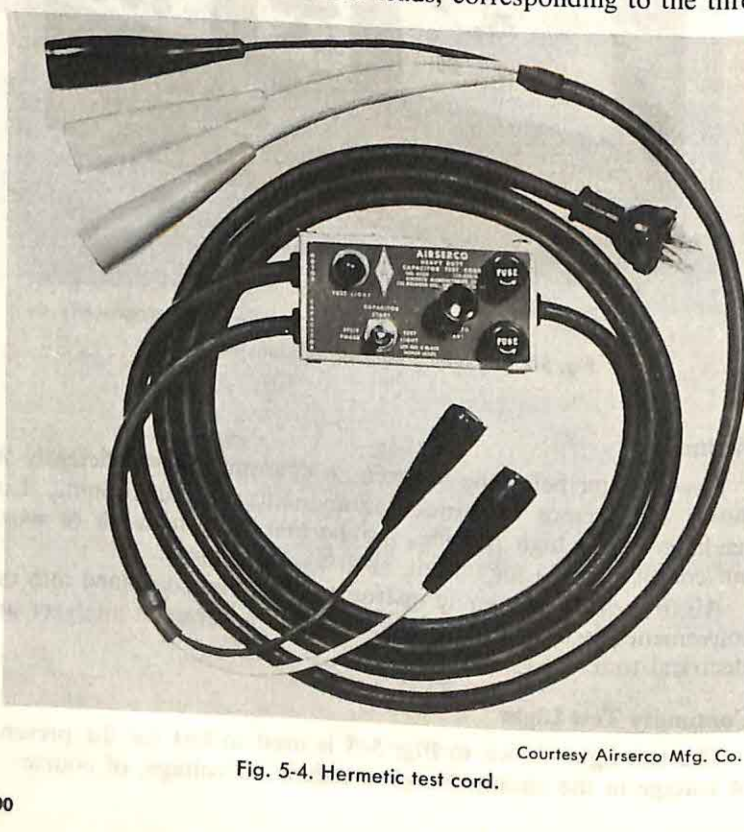


Fig. 5-3. Test-light circuit for checking the presence of voltage in the circuit.

Hermetic Test Cord

Used for isolating a unit from its circuit, the hermetic test cord pictured in Fig. 5-4 has a starting button to supply momentary current to the compressor. Three leads, corresponding to the three



Courtesy Airserco Mfg. Co.

Fig. 5-4. Hermetic test cord.

terminals on a compressor, are equipped with rubber boots of the same colors as the wires in the circuit.

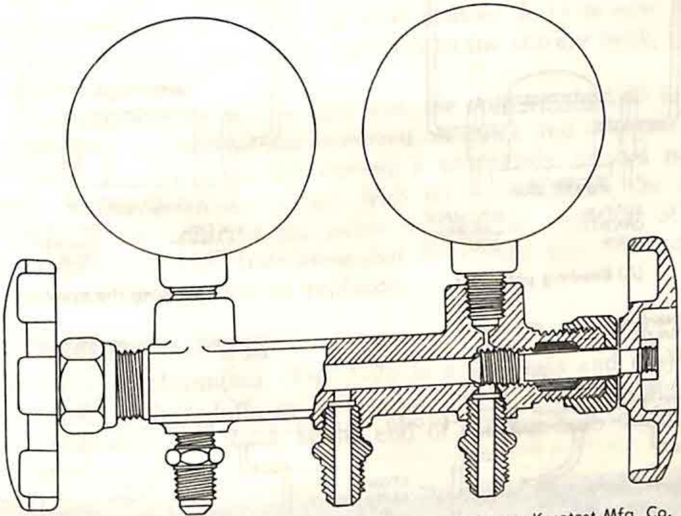
Miscellaneous

The serviceman quickly learns to carry with him an assortment of commonly used start and run capacitors, relays, and other components likely to cause trouble. A replacement check is made by using a jumper wire to substitute these parts for their equivalents in the circuit. One note of caution: Be sure the replacements have the same ratings and capacities.

PRESSURE, HUMIDITY, AND TEMPERATURE TESTING

Manifold-Gauge Set

A manifold-gauge set (Fig. 5-5) is indispensable for checking the high and low pressures of the system, as well as for purging



Courtesy Kerotest Mfg. Co.

Fig. 5-5. Manifold-gauge set.

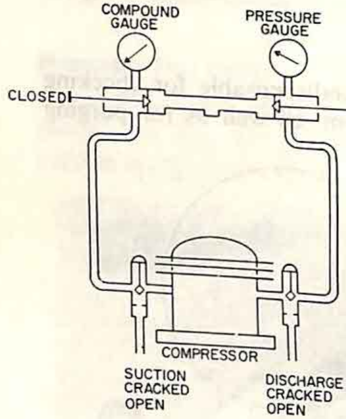
or charging a system. The gauge at the left in the illustration is a compound gauge that reads pressures both above atmospheric and below (to 30″ vacuum up to 60 psig). The compound gauge is connected to the low side of the system, at the suction service valve.

The gauge at the right in the illustration is a simple pressure gauge, calibrated to 300 psig. It is connected to the high side of the system, at the discharge service valve.

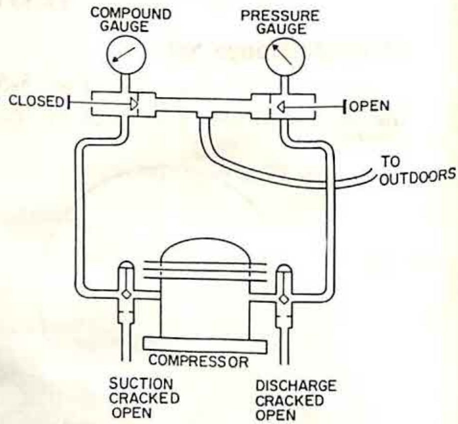
The valves have a common outlet, but separate inlets and gauge connections, permitting both the high- and low-side pressures to be measured simultaneously while the unit is operating. When both hand valves are closed, pressure is not shut off to the gauges, but they are effectively isolated from each other.

Fig. 5-6A shows the valve setting for reading pressures, and Fig. 5-6B shows the setting for purging the system. The settings for charging the system with refrigerant *vapor* into the low side, and with *liquid* refrigerant into the high side, appear in Figs. 5-6C and D.

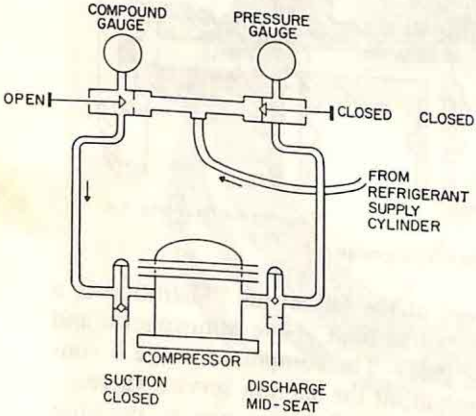
Note carefully the settings of the suction and discharge service valves (at the compressor) for each operation.



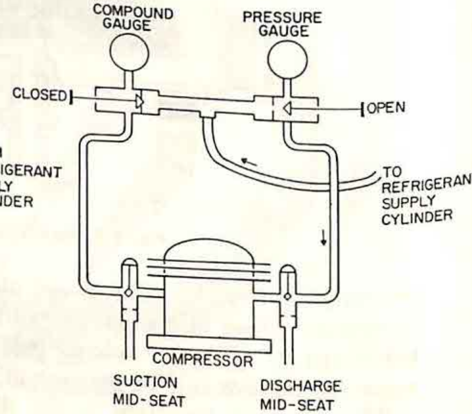
(A) Reading pressures.



(B) Purging the system.



(C) Charging to low side.



(D) Charging to high side.

Fig. 5-6. Manifold-gauge set in different arrangements of valves.

Flushing the Unit

A system that has been opened for repairs must be flushed to rid it of bits of solder and other foreign matter. Refrigerant R-11 is usually employed as a flushing element because it remains in a liquid state at or near atmospheric pressure and room temperature.

Normally the compressor is disconnected from the line when the unit is flushed. The liquid pump circulates the R-11 through the system. Foreign matter is washed out of the system and into the filter, which is stuffed with a pad of absorbent cotton and cheesecloth, where most of the solid impurities in the refrigerant are caught.

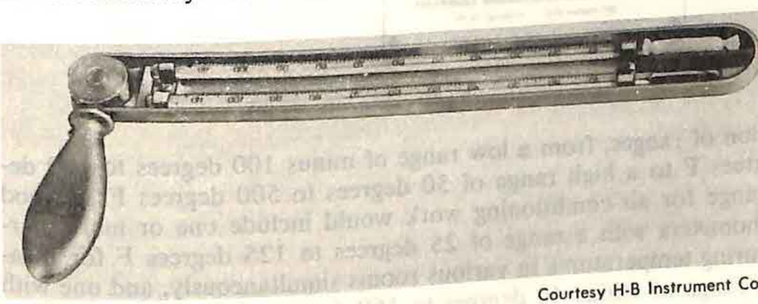
Next the liquid passes through a strainer-dryer, where moisture and the smallest particles of matter are trapped and isolated, as well as any acids which may have been created by a compressor motor burnout. The liquid refrigerant is cycled through the system until it changes from cloudy to clear, as seen through the sight glass in the pump outfit line.

By manipulating the valves, the low-pressure R-11 is now evacuated from the unit system and returned to the storage tank, clean and ready for re-use.

It is permissible to flush a unit with the compressor still in the line, provided no burnout has occurred. A quick and effective test for burnout can be made by wetting a chemically treated paper sample, similar to litmus paper, with refrigerant from the unit. A change in the color of the paper betrays the presence of the acids in the refrigerant, indicating that the compressor has burned out and must be repaired or replaced.

Sling Psychrometer

The sling psychrometer (Fig. 5-7) is a wet-bulb and dry-bulb thermometer with a built-in calibration for quickly reading the relative humidity. The wick at the end of the wet-bulb thermom-



Courtesy H-B Instrument Co.

Fig. 5-7. Sling psychrometer.

eter is dipped into distilled water. The psychrometer is held by the swiveled handle and whirled through the air, at a speed of about 150 revolutions per minute, for 15 to 20 seconds. More than one reading should be taken and an average struck, for greater accuracy.

Thermometers

A good bimetal thermometer (or several) is an important tool for the air-conditioner serviceman. Thermometers come in a selec-

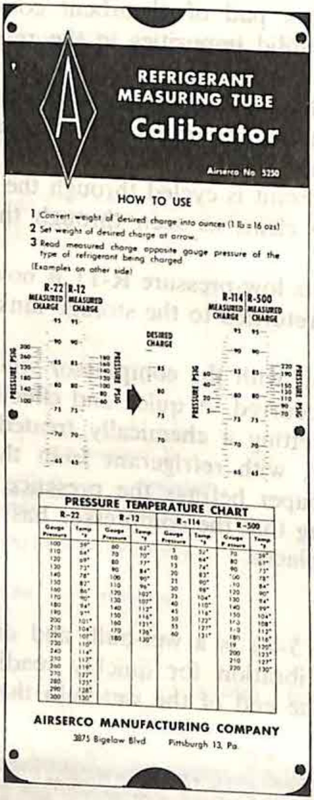


Fig. 5-8. Pressure calculator.

Courtesy Airserco Mfg. Co.

tion of ranges, from a low range of minus 100 degrees to 100 degrees F to a high range of 50 degrees to 500 degrees F. A good range for air-conditioning work would include one or more thermometers with a range of 25 degrees to 125 degrees F for measuring temperatures in various rooms simultaneously, and one with a range of minus 40 degrees to 160 degrees F for measuring heat of evaporation and condensation.

Pressure Calculator

Used in finding the head pressure when suction pressure, mean water temperature, ambient temperature, etc., are known, the pressure calculator in Fig. 5-8 is designed for all types of refrigerants.

INSTALLATION TOOLS

A regular complement of carpenter's tools will be required to handle all the demands made by different installations. Of particular importance are a good bubble level, a hacksaw, and a hand drill. Also have on hand a complete assortment of nuts and bolts, sheet-metal and wood screws, and other fasteners.

CHAPTER SIX

Air-Conditioner Repairs

Understanding the theory and operation of an air-conditioning system is vital to good servicing. A thorough job of servicing, particularly the operations of adding refrigerant and evacuating the system, require great care, deliberate planning, and constant practice.

As always, your first concern should be for safety—your own and others'. Remember that you are working with dangerous voltages. When checking the electrical components of a system, be sure to disconnect the power supply first if at all possible. If you use a test power cord, connect it to the power supply only long enough to complete the test. If you install new screws, bolts, or other fasteners, make sure that any extra length does not bring them into contact with an electrical component. This may sound elementary to you, but even the most sophisticated servicemen court disaster by careless habits and casual handling of electrical circuits.

Freon and other modern refrigerants, unlike those used in the past, are in themselves harmless. However, there are two characteristics of present-day refrigerants which require that they be handled with some degree of care. The first is the irritating compounds created when refrigerant is brought into contact with an open flame. These compounds will irritate the delicate membranes of the eyes, nose, and throat. Be sure to extinguish any open flames when handling refrigerant in containers or when purging a system.

The other potentially dangerous characteristic of any refrigerant is the pressure under which it is delivered. The greater the heat to which a supply cylinder is subjected, the higher the internal pressure will become. Never expose a cylinder of refrigerant to a temperature greater than 125 degrees F. Do not allow refrigerant supply

cylinders or storage drums, cans, etc., to remain in the direct rays of the sun in hot weather. Inexpensive adapters (Fig. 6-1) that attach to the supply cylinders are available, affording a hand grip as well as protection for the cylinder valve.

Remember, too, that refrigerants can cause frostbite, even when in momentary contact with the skin.

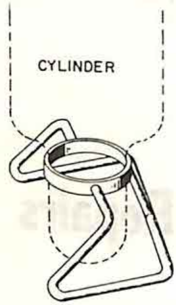


Fig. 6-1. Adapter stand holds supply cylinder in position for charging, prevents damage to cylinder valve.

ADDING AND REMOVING REFRIGERANT

Since most systems differ in their provision for evacuating or charging, this book cannot cover every method and technique used. However, the following principles can be applied to nearly any situation.

Refrigerant Supply Containers

Refrigerant is supplied in large cylinders (Fig. 6-2) holding anywhere from 5 to 150 pounds of various types of refrigerant. Refrigerant can be taken directly from these *supply cylinders*, or may first be transferred to smaller-capacity *service cylinders* as shown.

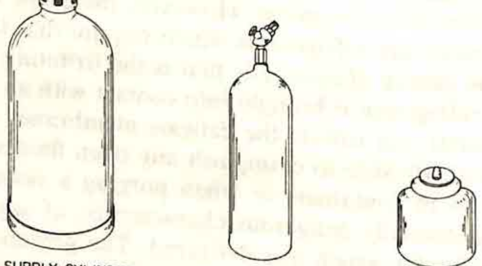


Fig. 6-2. Types of refrigerant containers.

Refrigerant for small charges is also supplied in cans holding from a few ounces to two or three pounds. Unlike the supply and service cylinders, these cans are disposable. An adapter at the top accepts a universal valve for opening the can and dispensing the contents.

Transferring Refrigerant to Service Cylinder

To transfer refrigerant to the service cylinder, first evacuate the cylinder with a high-vacuum shop pump. Then dehydrate it by immersing it in warm water (not over 125 degrees F) and continue the pumping. Close the service cylinder valve, stop the pump, and remove the pump connection. Arrange the service and supply cylinders as shown in Fig. 6-3. The cracked ice assures that the refrigerant will remain in a liquid state as it is delivered to the service cylinder.

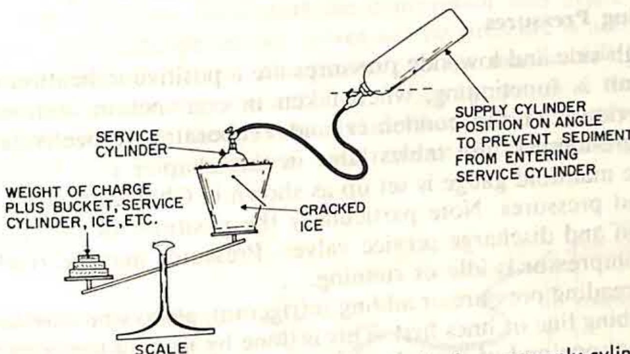


Fig. 6-3. Arrangement for charging a service cylinder from a supply cylinder.

Tighten the tubing line at the connection to the supply cylinder, but leave it loose at the service-cylinder connection to purge the tubing line. Crack open the supply-cylinder valve, permitting refrigerant to fill the tubing line, and allow some refrigerant vapor to escape through the loose connection. This effectively purges the line. Now tighten the connection, and open both valves.

Note the use of the weighing scale. The service cylinder and its pail of cracked ice, with tubing in position, are carefully weighed on the scale before charging begins. The desired weight of the charge is then added to the weights on the scale, causing the scale to tip out of balance. As the service cylinder fills, the scale again comes into balance. This indicates that charging is complete (i.e., the exact amount of refrigerant desired has been transferred to the service cylinder). As the scale begins to come into balance, close the supply-cylinder valve. Allow a few moments for the tubing line

to drain; then close the service-cylinder valve and disconnect the tubing.

Room Air Conditioners

Normally, sealed systems like those in room air conditioners have no suction and discharge service valves. Some have only a short length of process tubing, located in the suction line near the compressor, for partially evacuating the system so the compressor may be removed. Others have two process tubes, one in the suction line and the other in the liquid line, at or near the strainer at the compressor outlet.

Since it rarely, if ever, will be necessary to purge a sealed system or to add refrigerant, no valves are provided for this purpose. Sealed units which require refrigerant after servicing are given a whole new charge by first being flushed, then evacuated and dehydrated under rigidly controlled conditions.

Reading Pressures

High-side and low-side pressures are a positive indication of how the unit is functioning, when taken in conjunction with ambient temperature at the condenser and evaporator respectively. (See pressure-temperature tables later in this chapter.)

The manifold gauge is set up as shown in Chapter 5 (Fig. 5-6A) to read pressures. Note particularly the positions of the three-way suction and discharge service valves. Pressures may be read while the compressor is idle or running.

In reading pressure or adding refrigerant, always be sure to purge the tubing line or lines first. This is done by leaving the connections loose at one end of the tubing (at the service-valve end for adding refrigerant; at the manifold-gauge end for reading pressures) and admitting some refrigerant into the lines. Then tighten all connections and set the valves in appropriate positions. If the tubing lines are not purged, the air and moisture normally present in the tubing will be admitted into the system.

Amount of Refrigerant Charge

The refrigerant capacity and the kind of refrigerant to use are usually recorded on the unit nameplate. The type of refrigerant (R-11, R-12, R-22, etc.) cannot be changed in sealed systems, because of the delicate balance designed into the system.

The amount of refrigerant charge in a sealed system with a capillary restrictor is highly critical. If only a little more or less than the normal amount of refrigerant is in the system, the unit will not cool. However, in units equipped with separate receivers and expansion valves, the rated capacity may be exceeded without effect. In fact,

in charging these systems, a little more refrigerant than called for is added as a reserve supply.

Bleeding a System

Any air or moisture in a system must be removed. The presence of air is betrayed by pressure-temperature readings at variance with known pressure-temperature readings of pure refrigerant.

Any air in a system will mix intimately with refrigerant vapor, but will not mix at all with liquid refrigerant. To remove air from the system, therefore, it is only necessary to remove the refrigerant vapor. This is done by bleeding or purging the low side (see Fig. 5-6B for the arrangement of the manifold-gauge set, and settings of the suction and discharge service valves).

Connect a length of purging hose (¼″ ID and ½″ OD) to the common outlet on the manifold-gauge set and run it outdoors. Set the manifold-gauge valves so the compound valve is closed and the pressure valve is open. Now start the compressor and crack both the suction and discharge service valves so that pressure is admitted to the ports on both valves. The pressure-gauge needle will begin to drop as refrigerant vapor is expelled. When the pressure reaches the desired level, turn the suction and discharge service valves to their normal operating positions, and remove the manifold-gauge set and purging hose.

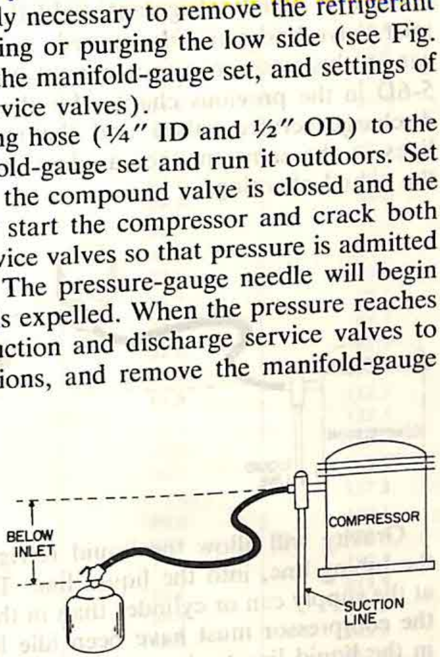


Fig. 6-4. Position of disposable can in adding refrigerant vapor to system.

(Note: Water-cooled systems having a regulating water valve operated by a pressure-sensitive device in the high-side vapor line will not show an increase in vapor pressure if there is air in the line. The presence of air in a water-cooled system is indicated by an abnormal consumption of water for cooling.)

Adding Refrigerant Vapor to Low Side

The disposable cans (Fig. 6-2) are useful and convenient for adding small amounts of refrigerant to a system. To add refrigerant vapor rather than liquid, hold the can below the inlet to the system, in an upright position as shown in Fig. 6-4. *Do not inject liquid refrigerant into the low side of a system.* The liquid will reach the compressor and damage it.

Connect the manifold-gauge set, as shown in Fig. 5-6C, attaching the tubing line to the can of refrigerant. Purge the tubing line and connections. Arrange the service valves as shown, and start the compressor. When the desired suction and discharge pressures are reached, stop the compressor. Place the service valves in their normal operating positions and disconnect the manifold-gauge set and tubing lines.

Adding Liquid Refrigerant to High Side

To add liquid refrigerant, hold the supply can higher than the inlet valve and point downward, as shown in Fig. 6-5. With the can in this position, vapor cannot enter the system. Refer to Fig. 5-6D in the previous chapter for the positions of the suction and discharge service valves and the manifold-gauge set. Purge the lines in the same manner as described previously before starting the actual charging.

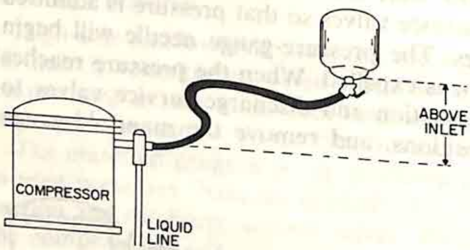


Fig. 6-5. Position of disposable can in adding liquid refrigerant.

Gravity will allow the liquid refrigerant to flow down through the tubing line, into the liquid line. The pressure must be greater at the supply can or cylinder than in the system. To insure the flow, the compressor must have been idle long enough for the pressure in the liquid line to drop and the temperature of the line lowered to approximately the ambient temperature. Hot cloths applied to the supply cylinder will hasten the flow.

PRESSURE-TEMPERATURE TABLES

The information in Tables 6-1 and 6-2 will be useful in checking the performance of an air-conditioning system. The figures in Table 6-1 are used for checking pressure-temperature relationships. Table 6-2 gives useful information about the properties of refrigerants.

Three refrigerants are listed in the tables—R-11, R-12, and R-22. Unit specifications refer by number or by chemical name to the type of refrigerant used in the system. Refrigerants are mar-

Table 6-1. Pressure Temperature Ratios of Saturated Refrigerant Vapor.

Temperature °F	R-11 Trichloromono-fluoromethane	R-12 Dichlorodi-fluoromethane	R-22 Monochlorodi-fluoromethane
−40	**28.4**	**11.0**	0.6
−35	**28.1**	**8.4**	2.7
−30	**27.8**	**5.5**	5.0
−25	**27.4**	**2.3**	7.6
−20	**27.0**	0.6	10.3
−15	**26.5**	2.4	13.3
−10	**26.0**	4.5	16.6
−5	**25.4**	6.7	20.2
0	**24.7**	9.2	24.1
5	**24.0**	11.8	28.3
10	**23.1**	14.6	32.9
15	**22.1**	17.7	37.9
20	**21.1**	21.0	43.3
25	**19.9**	24.6	49.0
30	**18.6**	28.5	55.2
35	**17.2**	32.6	61.9
40	**15.6**	37.0	69.0
45	**13.9**	41.7	76.6
50	**12.0**	46.7	84.7
55	**9.9**	52.0	93.3
60	**7.7**	57.7	102.5
65	**5.3**	63.8	112.2
70	**2.6**	70.2	122.5
75	0.1	77.0	133.4
80	1.6	84.2	145.0
85	3.2	91.8	157.2
90	5.0	99.8	170.1
95	6.9	108.3	183.7
100	8.9	117.2	197.9
105	11.1	126.6	212.9
110	13.4	136.4	228.7
115	15.9	146.8	245.3
120	18.5	157.7	262.6
125	21.3	169.1	—
130	24.3	181.0	—
135	27.5	193.5	—
140	30.8	206.6	—
145	34.4	220.3	—

Figures in light face type are psig. Figures in bold face are inches of mercury vacuum.

keted under many trade names, the most familiar perhaps being *Freon*, a product of DuPont. Trade names are usually followed by a number to identify the type of refrigerant, as *Freon 11*, *Freon 12*, etc.

Two other refrigerants, not listed in the tables, are R-113, used in heavy industrial applications of 50 tons of cooling or more, and R-114A, used in commercial, industrial, and household refriger-

Table 6-2. Properties of Refrigerants*.

Property	R-11	R-12	R-22
Chemical formula	CCl_3F	CCl_2F_2	$CHClF_2$
Latent heat of evaporation at 5°F (Btu/hr)	84.0	68.2	93.6
Boiling point at 14.7 psia in °F	74.7°	−21.6°	−41.4°
Freezing point at 14.7 psia in °F	−168°	−252°	−256°
Critical temperature in °F	388°	234°	205°
Critical pressure in psia	635	597	716
Compression ratio (between 86° and 5°F)	6.24	4.08	4.06
Quantitative circulation per ton of refrigeration			
Pounds of refrigerant per minute	2.96	4.00	2.89
Cubic inch per minute	56.0	85.6	68.0
Flammability		NONE	

* Based on a temperature of 5°F. at the evaporator and 86°F. at the condenser.

ation. R-11, as pointed out previously, is a low-pressure refrigerant used in some centrifugal motor compressors for multiroom cooling. R-22 is used in applications requiring very low temperatures such as freezers and larger package units. R-12, the most widely used refrigerant in room air conditioners, has desirable pressure ranges adaptable to the light tubing used in these units.

By measuring the pressure at the evaporator or condenser, coupled with a temperature reading, a diagnosis of the system can be made—whether or not air is present in the lines, or whether the level of refrigerant is too high or too low. Depending on other symptoms, pressure-temperature readings can give us information, too, about the functioning of the compressor and other components in the system.

The pressure-temperature relationship of pure refrigerants is constant. Thus, any deviation from normal could mean air or other impurities in the system.

ELECTRICAL TESTS

The performance of refrigerant under given conditions is predictable and unvarying. As a result, it is possible to gain information about the mechanical functioning of an air-conditioning system from electrical data, sometimes combining this data with information about pressures and temperatures. Following are some electrical tests that help in diagnosing the cause of air-conditioner troubles:

Temperature Split/Wattage Test

Information about air flow, compressor functioning, amount of charge, and other suspected troubles can be confirmed by temperature readings taken at the return room-air inlet and the cooled-air

outlet, coupled with readings from a wattmeter. This information is then compared with the specifications published in the manufacturer's service literature.

The *difference* in temperature between the inlet and outlet air flow is called a *split*. High or low splits refer to a greater or smaller temperature difference, respectively. A low split, meaning a small difference between inlet and outlet temperature, indicates insufficient cooling, and a high split, too much cooling.

Each of the following combinations of high and low splits and wattages has a special significance to the serviceman.

High Temperature Split, Low Wattage—An indication that an insufficient volume of air is passing over the evaporator. The lesser volume of air gives up more of its heat to the evaporator, is delivered to the room at a colder temperature than normal. Look for obstructions in the air-flow systems.

Low Temperature Split, Low Wattage—This indicates that the evaporator is starved for refrigerant. Look for restrictions in the capillary or expansion valve (if there is one), air in the system, and other mechanical faults. To find a restriction in a capillary tube or in any other tubing in the liquid line, feel the line for a cold spot, which indicates a restriction. If no cold spots are present, the charge is low, possibly because some of the refrigerant has leaked away. Check for leaks in the system.

No Temperature Split, Low Wattage—This indicates a nonfunctioning compressor. Possible causes may be a broken shaft, valves stuck open, etc.

High Temperature Split, High Wattage—Usually this indicates too much refrigerant in the system. Confirm by checking for sweating throughout the evaporator passes and the suction line. Too high a refrigerant overcharge will cause the compressor protector to open the circuit frequently or even permanently.

Low Temperature Split, High Wattage—The high wattage indicates the compressor is working too hard. Look for sweating on the suction line all the way to the compressor, a sign that some liquid refrigerant is reaching the compressor. The system must be drained and the compressor, needle valves, and other components must be checked for damage.

Line Voltage

Low or high line voltage is a source of trouble in any air conditioner. When checking the line voltage, turn on any other appliances on the same circuit that ordinarily operate at the same time as the air conditioner. The air conditioner should be running at full load during the test. Also make sure the wire size of any extension cords is adequate.

Switches

With an ohmmeter, check for continuity across the terminals at each switch setting (HIGH FAN, LOW FAN, etc.). Caution—before making any tests with an ohmmeter, remove the power plug from the outlet to prevent damaging the instrument.

Overload Protector

Use a wattmeter and a jumper wire to check the overload protector (Fig. 6-6). The jumper should be connected between terminals 1 and 2 on three-terminal overloads (A and B on some compressors). If higher than the specified wattage is consumed the overload protector is probably good if it opens the circuit, and you should suspect some other component of the system. If wattage consumption is normal, and removal of the jumper stops the compressor, the protector is defective and should be replaced.

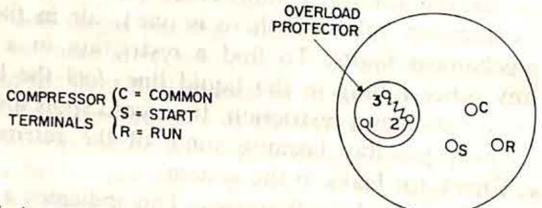


Fig. 6-6. Arrangement of terminals on typical sealed-system compressor and overload protector.

Thermostat

Thermostats are checked for continuity across the terminals, using an ohmmeter. Remove the wires to the thermostat, turn the thermostat to its high-limit setting, and connect the ohmmeter. No reading indicates a faulty circuit in the thermostat.

Start Capacitor

If the motor compressor draws excessive current or hums excessively while starting, or does not start at all, the start capacitor may be faulty.

A defective capacitor frequently has a white residue at or near its terminals. In the absence of any visual signs, the best test is to replace the old start capacitor with one of exactly the same specifications.

You can also check a capacitor by making a resistance check; however, it must first be discharged. To do so, pull the power plug from the wall outlet, and short across the capacitor terminals with a jumper wire. Set the ohmmeter at the 1-megohm scale. Take a

reading, then discharge the capacitor, reverse the leads, and take another reading. If the ohmmeter needle stabilizes at 30,000 ohms or less, the capacitor should be considered leaky and should be replaced.

Run Capacitor

Unexplainable excessive power consumption indicates a faulty run capacitor. Make the ohmmeter test described for the start capacitor. If the needle comes to zero, then slowly returns to infinity, the capacitor is functioning properly. If the needle does not move at all, the capacitor is open. If the needle comes to rest somewhere between zero and infinity, the capacitor is leaky. In either of the latter two cases, the capacitor should be replaced.

Fan-Motor Capacitor

If a faulty fan-motor capacitor is suspected, the simplest check is to replace it with one known to be good. Substitute; do not merely bridge across the suspected capacitor.

Relays

Excessive wattage consumption of the compressor upon reaching normal run speed could indicate a relay that is not properly dropping out of the circuit after start. Low line voltage will sometimes cause the relay to "chatter." To check, short out the relay with a jumper wire across the proper terminals. (Refer to the wiring diagram on manufacturers' service literature for the correct terminals to jump.) Apply the jumper wire during the compressor run, for no more than two or three seconds at a time. If the compressor runs properly during the test, a faulty relay is indicated.

Checking Circuit Lines

Use a test cord to replace suspected lines in the circuit. For example, if a fan motor does not start, disconnect the leads to the motor and connect the test-power cord. If the fan motor starts when the test cord is plugged into the wall outlet, the failure is in the lines to the motor, in the switches, or in the electrical connections.

TROUBLESHOOTING GUIDE

The following symptoms are the signs of trouble in the system. Each symptom is followed by a number of possible causes and remedies. The list is by no means complete, but it will serve as a guide to the more common failures and causes of failure in any air-conditioning system.

Compressor and Fan Motor Do Not Run

1. No power to system. Check supply lines, outlets, fuses, switches, internal circuitry. If a fuse is blown, check for possible high voltage, or shorts in the line. Merely replacing a fuse does not eliminate the cause, and may damage a valuable component.
2. Loose or faulty connections, switches. Adjust or replace as necessary.

Fan Motor Runs, but Compressor Does Not Function

1. Defective compressor starting capacitor. See capacitor test under "Electrical Tests" above.
2. Circuit to compressor open. Check circuit, switches, terminals, overload, relays.
3. Low voltage may be a contributing cause. Install transformer (available from some manufacturers for this purpose).
4. Defective thermostat or circuit to thermostat. Check as described under "Electrical Tests."
5. Defective motor compressor. When all other tests fail to turn up faulty electrical components, the compressor may be at fault. Apply power directly to it through test-power cord. If compressor fails to run, it must be replaced. Do not attempt to start a "stuck" compressor by applying a momentary surge of high voltage, as some servicemen do. This is only a temporary remedy which may damage the compressor.

   When a motor compressor burns out, the system must be thoroughly flushed and evacuated as described previously. All traces of burned insulation and varnish, carbon and other foreign matter must be removed from the system, as well as certain harmful acids which form upon burnout. The condenser, evaporator, and segments of the lines should be flushed separately. Do not attempt to re-use the capillary tubing. After thorough flushing, the system is reassembled, all tubing is resoldered securely, and flushing is again performed (without the capillary tubing in the line), to get out all bits of solder and other foreign matter that may have collected when the system was reassembled. The capillary is then soldered into the line, and refrigerant added to the system to test for leaks. Now proceed with normal evacuation, charging, etc.

Fan Runs, Compressor Starts, Then Soon Stops

1. Overload protector is operating. Check for high wattage caused by high voltage, clogged condenser, or any restric-

tion in refrigerant line. Check for shorts in compressor circuit or relay.
2. Condenser air flow blocked, or outside temperature on unit casing so high that it approximates temperature of refrigerant in condenser. Free the air flow or provide an awning for shading the outdoor portion of the unit.
3. Internal trouble in compressor. Check for wattage consumption as given in service literature. If abnormally high and no other trouble can be found in circuit, replacement of compressor is indicated.

No Air Flow, Compressor Runs

1. This is a serious situation, regardless of the cause. The air conditioner should never be permitted to run without the fan. In fact, most air conditioners are so wired that it is impossible to run the compressor unless the fan motor is operating. Look for binding of the fan-motor shaft or blades, defective fan motor, shorted fan-motor relays or capacitors.

Noisy Operation

1. Check for misaligned fan blades, loose tubing connections, loose compressor mountings, defective fan-motor bearings, and other obvious mechanical faults.
2. Sometimes, after a prolonged shutdown, refrigerant will be absorbed in the compressor lubricating oil. This will make a noise like bubbling liquid. It will disappear after the unit is in operation for a time.
3. If the noises appear to come from within the compressor, and do not stop after the unit has been in operation for a short while, internal trouble is indicated, such as broken mounting springs, loose shaft bearings, or worn piston rings. Compressor should be replaced.
4. Noise can result from the vibration of tubing or from "harmonics." Run your hand over the refrigerant tubing, particularly where it makes a loop before reaching the compressor. At the place where the touch of your hand causes the noise to stop, tape or clamp the tubing to the nearest inert component, bracket, etc.

Insufficient Cooling

1. Look first for dirty evaporator and condenser coils. Even a light coating of dust can interfere with heat transfer to or from these vital components. Remove all dust with a vacuum cleaner; then see why it is entering the interior of the cabinet. Caution the operator never to run the unit without an air filter

in place, and to replace or clean the filter at frequent intervals, according to the manufacturer's operating instructions.

2. Those units that use the condensate from the evaporator for extra cooling of the condenser should be examined for proper adjustment of the slinger ring on the condenser fan.
3. Low fan speed may be the cause of insufficient cooling. Check the voltage, electrical circuit, and fan lubricant, and look for bent or broken fan blades.
4. Too much superheated vapor in the evaporator passes will cause insufficient cooling. Look for leaks in the refrigerant system. Units with expansion valves require adjustment of the valve, added refrigerant, or both. In sealed units with capillary restrictor tubing, look for cold spots in the liquid line; they denote an internal obstruction. Check pressure-temperature relationship against standards in service literature. Check also for low refrigerant level, although in sealed systems this is only a remote possibility if no leaks are apparent.
5. Ice on evaporator coils. Coupled with insufficient cooling, this is evidence of a low volume of air passing over the evaporator. Check air passages, fan-motor operation, restrictions at return air inlet. *Very important:* Check to see whether cooled air is passing directly from the air-conditioner outlet grilles to the return air intake. This is a possibility if the air conditioner is located in a corner of a room where cooled air may be prevented from freely circulating. An adjustment of the grilles, to direct air toward the open space in the room, will frequently correct this situation. In extreme cases, duct-work must be provided to carry the cooled air away from the return air inlet.

   Ice on the evaporator, along with *too much* rather than insufficient cooling, is evidence of a defective thermostat. Check and replace if necessary.

Sweating

1. As mentioned at the beginning of this chapter, sweating of the suction line is an indication of excess refrigerant in the system. For systems with expansion valves, this is corrected by adjusting the valve to admit less refrigerant into the evaporator. This increases the length of travel of the superheat at the end of the evaporator passes. In sealed systems, sweating may be caused by some obstruction in the path of the air flow, either in the condenser or evaporator. Rarely, if ever, will sweating be caused by too much refrigerant in a sealed system.

SUMMARY

Air-conditioner repairs and servicing are virtually impossible without a good knowledge of *why* and *how* the refrigerant and components react the way they do. All air-conditioning men must bear in mind the why and how of a situation so that they may better understand where to look for the trouble, and what kind of trouble to expect.

A constant review of theory and operation will help servicemen more than learning symptoms and remedies by heart. Understanding where to look for the trouble means not only saving valuable time, but eliminating the cause of the trouble and not just the superficial symptom as well.

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abc's of AIR CONDITIONING

by ERNEST TRICOMI

In this book, Mr. Tricomi shows how the natural laws of liquids and gases, and heat transference have been fully exploited in the design of the modern air conditioner. The book progresses from a discussion of basic principles, through construction details and types of air-conditioning systems, to installation, troubleshooting, and repairing.

The first chapter gives a thorough grounding in the natural laws governing temperature, heat transference, behavior of liquids and gases, cooling by evaporation, effects of pressure and vacuum, and other related phenomena. The various mechanisms for applying these principles in an air-conditioning unit are described.

Chapter 2 discusses types of air-conditioning systems: individual-room, centralized, and residential types. Chapter 3 explains the electrical parts of a system. Succeeding chapters take up system installation, tools and test equipment, and repair procedures.

Whether your interest is merely in finding out how and why an air conditioner works or extends to the point of servicing and repair, you will find valuable information in this book for you.

ABOUT THE AUTHOR

Ernest Tricomi is a free-lance writer on many subjects, including general business, technical and art. For many years, he has been associated with North American Publishing Company as an editorial expediter. He is a colonel in the U.S. Army Reserve, where he serves as instructor in the Group Study Program of the Industrial College of the Armed Forces. He is also the author of the popular SAMS book, *How to Repair Major Appliances.*